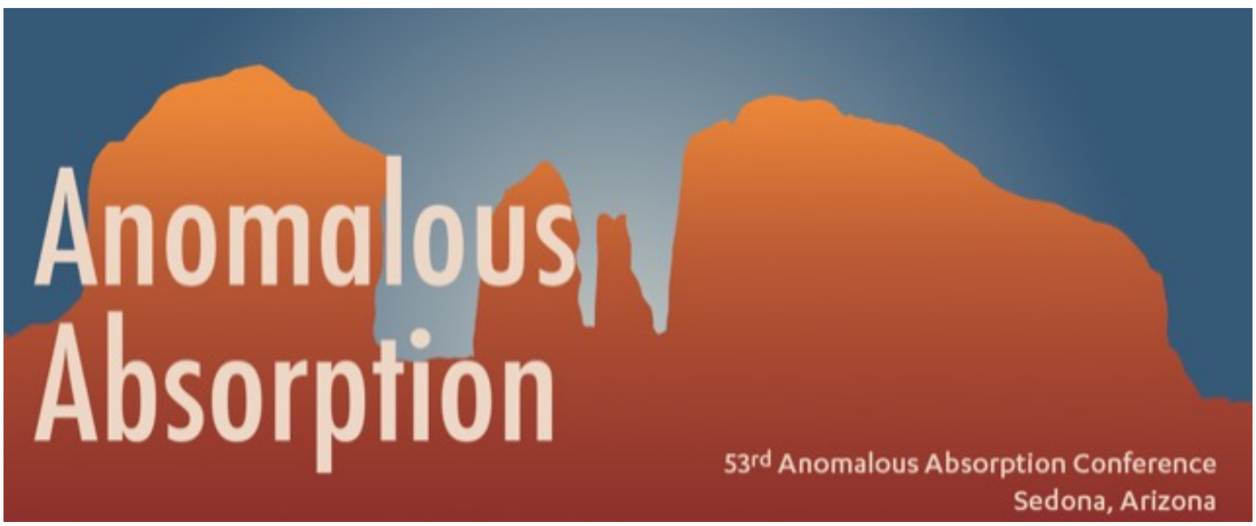
53rd Anomalous Absorption Conference

May 11-16, 2025

Program



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Anomalous Absorption

53rd Anomalous Absorption Conference
Sedona, Arizona

Monday, May 12, 2025				
	Chair: Pierre Michel, LLNL			
8:25-8:30 AM	Welcome	Frank Tsung	UCLA	tsung@physics.ucla.edu
8:30-9:00 AM	New effects from magnetized cross-beam energy transfer	John D. Moody	LLNL	moody4@llnl.gov
9:00-9:20 AM	Status of the magnetized cross beam ener gy transfer (MagCBET) campaign	Yuan Shi	University of Colorado	Yuan.Shi@colorado.edu
9:20-9:40 AM	Simulations of LPI-generated hot electrons with an applied external magnetic field	Edoardo Rovere	UCSD	erover@ucsd.edu
9:40-10:00 AM	An early look at laser plasma interaction at a next generation indirectly driven inertial confinement fusion facility	Thomas Chapman	LLNL	chapman29@llnl.gov
10:00-10:20 AM	Two-dimensional Vlasov -Fokker-Planck modeling of electron transport and magnetic field generation for hohlraums	Mark Sherlock	LLNL	sherlock3@llnl.gov
10:20-10:40 AM	Break			
	Chair: Dustin Froula, LLE/U Rochester			
10:40-11:10 AM	Optimal bandwidth spectra for minimizing T wo Plasmon Decay	Archis Joglekar	Ergodic LLC	Ajog@lle.rochester.edu
11:10-11:30 AM	Impact of smoothing by spectral dispersion on laser -plasma interactions in NIF indirect -drive experiments	Henry Meyer	LLNL	meyer58@llnl.gov
11:30-11:50 AM	Mitigation study of laser plasma interactions with broadband lasers	Khanh Linh Nguyen	Focused Energy	linh.nguyen@focused-energy.co
11:50-12:10 PM	Gaussian Laser Beam Filamentation Influenced by Additional Smoothed Laser Beams	Kyle McMillen	LLE	kmcm@lle.rochester.edu
12:10-12:30 PM	On the influence of optical smoothing technics on cross -beam energy transfer	Yann Lalaire	CEA	ylalaire@gmail.com
12:30-1:30 PM	Lunch:			
	Chair: Tom Chapman, LLNL			
7:00 - 8:00 PM	LaserNetUS: the first five years of scientific discovery	Félicie Albert	LLNL	albert6@llnl.gov

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POSTER SESSION 1

Monday, May 12, 2025

1	Ben Winjum	Parameter scan of stimulated Raman scattering in a magnetic field	bwinjum@ucla.edu
2	Damyn Chipman	The Effects of Coulomb Logarithm Model on Laser Enegy Deposition into Materials	dchipman@lanl.gov
3	Frank Tsung	Particle-in-Cell Simulations of rescattering under IFE relevant conditions	tsung@physics.ucla.edu
4	Justin Jeet	Diagnosing burning plasmas at the National Ignition Facility via reaction-in-flight deuterium-tritium fusion neutron spectral measurements	jeet1@llnl.gov
5	Luis S. Leal	X-ray generation in foam filled hohlraums via non-thermal electrons accelerated by laser plasma interactions	leal9@llnl.gov
6	Matthias Geissel	Neutron diagnostics and neutron generation with Z-Petawatt	mgeisse@sandia.gov
7	Olivier Larroche	An improved extended hydrodynamics model for interpenetrating plasmas	olivier.larroche@cea.fr
8	Sarah Hansen	Using Direct Drive Data to Validate Los Alamos National Laboratory's xRage Common Model Framework	sehansen@lanl.gov
9	Mitchell Sinclair	Does the WKB approximation predict the Amplification Length of the bSRS instability in a Density Gradient Plasma ?	mdsinclair@ucla.edu
10	Andreas Kemp	Modeling stimulated Brillouin backscatter from the inner laser cones during indirect drive inertial confinement fusion experiments at the National Ignition Facility	kemp7@llnl.gov
11	Alex Seaton	Assessment of the Cross-Beam Energy Transfer (CBET) Risk for Polar Direct-Drive Wetted-Foam Designs	agseaton@lanl.gov
12	Nuno Lemos	Backscatter measurements of laser-plasma interactions relevant to an upgraded National Ignition Facility laser system	candeiaslemo1@llnl.gov

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Tuesday, May 13, 2025

	Chair: Alison Christopherson, Xcimer Energy			
8:30-9:00 AM	High-yield implosions using DT wetted foam for inertial fusion energy (IFE)	Darwin Ho	LLNL	ho1@llnl.gov
9:00-9:20 AM	Perusing through high yield experimental data at the National Ignition Facility	Laurent Divol	LLNL	divol1@llnl.gov
9:20-9:40 AM	The Impact of Fuel-Ablator Mix on Achieving Ignition in Inertial Confinement Fusion	Benjamin Bachmann	LLNL	bachmann2@llnl.gov
9:40-10:00 AM	Reduced hohlraum gas fill density for improved inner beam propagation and implosion symmetry	Joseph Ralph	LLNL	ralph5@llnl.gov
10:00-10:20 AM	Relating Metrology to Performance in Recent High Yield Implosions on the National Ignition Facility	Brian M. Haines	LANL	bmhaines@lanl.gov
10:20-10:40 AM	Break			
	Chair: Joe Ralph, LLNL			
10:40-11:10 AM	Two-sided target designs for high standof IFE implosions	Alison Christopherson	Xcimer Energy	achristopherson@xcimer.net
11:10-11:30 AM	A common model framework for advancing physics models in radiation hydrodynamic codes for inertial fusion enegy	John Kline	LANL	jkline@lanl.gov
11:30-11:50 AM	Modeling for a Planar Heterogeneous Ablation Experiment on OMEGA*	Blake Wetherton	LANL	wetherton@lanl.gov
11:50-12:10 PM	Analysis of externally-driven hohlraums to support hybrid drive for the Xcimer IFE concept	Mark Schmitt	LANL	mjs@lanl.gov
12:10-12:30 PM	Designing a High Yield Polar Direct Drive Target with Los Alamos National Laboratory's xRage Common Model Framework	Camille Samulski	LANL	csamulski@lanl.gov
12:30-1:30 PM	Lunch:			
	Chair: Archis Joglekar, Ergodic LLC			
7:00 - 8:00 PM	Inverse Bremsttrahlung Absorption	David Turnbull	LLE	dpturnbull@lle.rochester.edu

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POSTER SESSION 2

Tuesday, May 13, 2025

1	Steven Langer	pF3D and the Journey to Exaflops *	langer1@llnl.gov
2	Blagoje Djordjevic	Integrated radiation-magneto-hydrodynamic simulations of Magnetized Burning Plasmas	djordjevic3@llnl.gov
3	Devdigvijay Singh	Achromatic Plasma Lenses	dssingh@stanford.edu
4	Izzy Thomas	Wave breaking in helical plasma waves	ithomas@uscd.edu
5	Kale Weichman	Progress in kinetic modeling of hot electron production by two -plasmon decay with bandwidth and speckle	kweic@lle.rochester.edu
6	Nicholas Ruof	Improving ICF Implosion Performance by Reducing its Residual Kinetic Energy	ruof1@llnl.gov
7	Rick Olson	Physics of direct-drive wetted foam ICF capsules*	reolson@lanl.gov
8	Shaun Kerr	Resolving anomalous ion temperatures on igniting shots at the National Ignition Facility using a gamma-based nToF	kerr24@llnl.gov
9	Wojciech Rozmus	Bow shock characteristics and ion heating in a plasma flowing across randomized laser beams .	wrozmus@ualberta.ca
10	Mikhail Belyaev	pF3D simulations of filamentation in Au foil reflection experiments at the NIF	belyaev1@llnl.gov
11	Nuno Lemos	Development of a transmitted beam diagnostic at the National Ignition Facility (NIF)	candeiaslemo1@llnl.gov

Wednesday, May 14, 2025				
	Chair: Laurent Divol, LLNL			
8:30-9:00 AM	Multi-Species Hydrodynamics in Ignition -Scale Hohlraums on the National Ignition Facility	Drew Higginson	LLNL	higginson2@llnl.gov
9:00-9:20 AM	First Indirectly Driven Liquid -DT Filled Double Shell Implosions at the National Ignition Facility	Sasi Palaniyappan	LANL	sasi@lanl.gov
9:20-9:40 AM	Post-Shot Simulations of Liquid-DT Filled Double Shell Experiments	Sara Negussie	LANL	snegussie@lanl.gov
9:40-10:00 AM	3D simulations of density perturbations in plastic foil seeded by foam microstructure	Adrien Pineau	LLE	apineau@lle.rochester.edu
10:00-10:20 AM	Low-mode nonuniformity in direct-drive implosions due to laser-smoothing techniques employed on OMEGA	Dana Edgell	LLE	dedg@lle.rochester.edu
10:20-10:40 AM	Break			
	Chair: Mark Schmitt, LANL			
10:40-11:10 AM	Precision single-shot measurements of plasma conditions using a broadband probe	Andrew Longman	LLNL	longman1@llnl.gov
11:10-11:30 AM	Modeling the Impact of THOR Windows on Capsule Implosion Symmetry	Ryan Lester	LANL	RLester@lanl.gov
11:30-11:50 AM	A Machine Learning-Driven Solution for Denoising Inertial Confinement Fusion Images	Asya Akkus	LANL	aakkus@lanl.gov
11:50-12:10 PM	Updates on Nuclear Imaging Capabilities at the National Ignition Facility	Mora Durocher	LANL	mdurocher@lanl.gov
12:10-12:30 PM	Particle-in-Cell Simulations of Burning Capsule Implosions	Johannes J. van de Wetering	LLNL	vandeweterin1@llnl.gov
12:30-1:30 PM	Lunch:			
6:00-7:00 PM	**Reception**			
7:00 - 8:00 PM	**Banquet + Stargazing**			

Thursday, May 15, 2025

	Chair: Yuan Shi, U. Colorado			
8:30-9:00 AM	Nonlinear Modeling of Photochemically-Induced Gaseous Optical Elements	Albertine Oudin	LLNL	oudin1@llnl.gov
9:00-9:20 AM	Characterization of photochemically-induced transient gas gratings as final optics for inertial fusion enegy lasers	Ke Ou	Stanford	ouke025@stanford.edu
9:20-9:40 AM	Understanding and managing optics damage from laser-plasma instabilities on the NIF	Pierre Michel	LLNL	michel7@llnl.gov
9:40-10:00 AM	Laser-Plasma Instabilities Driven by 1ω Pulses at Shock Ignition Conditions	Ben Gosling	LANL	b.gosling@warwick.ac.uk
10:00-10:20 AM	Xcimer's LPI risk assessment and mitigation program	Joshua Ludwig	XCIMER Energy	jludwig@xcimer.net
10:20-10:40 AM	Break			
	Chair: Jason Myatt, U Alberta			
10:40-11:10 AM	Expanding Thomson Scattering analysis to 2D electron velocity distributions	Avi Milder	LLE	amild@lle.rochester.edu
11:10-11:30 AM	Ray tracing model of Thomson scattering spectra including inhomogeneities and stimulated scatterings	Daniel Carleton	U. Alberta	dcarleto@ualberta.ca
11:30-11:50 AM	Investigation of Raman Sidescattering in Indirect Drive Experiments on the OMEGA Facility	Kévin Vilayphone	CEA	kevinvilay@gmail.com
11:50-12:10 PM	Impact of the near-forward stimulated Brillouin scattering in ICF experiments	Charles Ruyer	CEA	c.ruyer@gmail.com
12:10-12:30 PM	Anomalously strong density fluctuations in plasmas subject to stimulated Raman scattering of nanosecond laser pulses	Christophe Rousseaux	CEA	christophe.rousseaux@cea.fr
12:30-1:30 PM	Lunch:			
	Chair: Mario Manuel, GA			
7:00 - 8:00 PM	Center for Matter under Extreme Conditions Energy Transport in HED Plasmas and Applications in Laser- and Pulsed-power-driven Experiments	Petros Tzeferacos	University of Rochester	p.tzeferacos@rochester.edu

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POSTER SESSION 3

Thursday, May 15, 2025

1	Jason Myatt	Planar LPI experiments on the Laser Megajoule: first results.	myatt@ualberta.ca
2	Caleb Redshaw	Radiative Effects on Particle Direction in Counterpropagating Laser Pulses	credshaw@stanford.edu
3	Enac Gallardo-Diaz	Impact of High-Z dopants in implosion core hydrodynamics	enac@lanl.gov
4	Jan Velechovsky	Hydrodynamic modeling of shear-driven mixing layers	jan@lanl.gov
5	Kevin Ma	Simulations of electron and radiation preheat effects in laser-shocked 3D-printed plastic lattice media	kevinhma@lanl.gov
6	Matthew J. Carrier	Resistive Magnetohydrodynamic FLAG Simulations of Instability Growth in the Double Cylinder Experiment	matthew.carrier@lanl.gov
7	Maria Almanza	Controlling Brillouin amplification with flying focus pump beams	almanzam@physics.ucla.edu
8	Scott Wilks	Laser Wavelength Dependence of Particle Acceleration Mechanisms in High Intensity Laser Solid Density Plasma Interactions	wilks1@llnl.gov
9	Sida Cao	Transmission Plasma Holograms for Generation of High-Intensity Pulses Carrying Orbital Angular Momentum	sidacao@stanford.edu
10	Andrey Solodov	Simulations of coronal plasma hydrodynamics in the laser–plasma interaction experiments at the Laser Mégajoule	asol@lle.rochester.edu
11	Eli Feinberg	Modeling thermal radiation waves in the Mooncat NIF experiment	efeinberg@lanl.gov

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Friday, May 16, 2025				
	Chair: Benjamin Winjum, UCLA			
8:30-9:00 AM	Simulations of self-magnetization in expanding high-energy-density plasmas	Kirill Lezhnin	PPPL	klezhnin@pppl.gov
9:00-9:20 AM	Novel high-power and high efficiency OEC laser-based high-gain shock ignition	Atsushi Sunahara	Blue Laser Fusion	asunahara@bluelaserfusion.com
9:20-9:40 AM	Experimental observations of the non-resonant streaming instability during the early stages of quasi-parallel collisionless-shock formation	Mario Manuel	GA	mmanuelmac@gmail.com
9:40-10:00 AM	Preliminary results of planar experiments to characterize shock properties of wetted foams	Zaarah Mohamed	LANL	zlm@lanl.gov
10:00-10:20 AM	Self-similar growth rate in Rayleigh-Taylor and Richtmyer-Meshkov instabilities	Baolian Cheng	LANL	bcheng@lanl.gov
10:20-10:40 AM	Break			
	Chair: A. Sunahara, Blue Laser Fusion			
10:40-11:10 AM	Quality-preserving laser plasma ion beam booster via hollow-channel magnetic vortex acceleration	Marco Garten	LBNL	mgarten@lbl.gov
11:10-11:30 AM	A Path for Improving Laser Based Electron Radiography to Probe High-Z, HED Plasmas	Gerrit Bruhaug	LANL	gbruhaug@lanl.gov
11:30-11:50 AM	Optically probing magnetic fields in near critical density laser-produced plasmas	Audrey Farrell	UCLA	audfarrell@g.ucla.edu
11:50-12:10 PM	Flow induced beam deflection measurements in ablation plasmas	Colin Bruulsema	LLNL	bruulsema1@llnl.gov
12:10-12:30 PM				
Box Lunch + See you in 2026				

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New effects from magnetized cross-beam energy transfer*

J. D. Moody[1], B. B. Pollock[1], L. Leal[1], Y. Shi[2] and D. J. Strozzi[1]

[1]Lawrence Livermore National Laboratory, Livermore, CA 94550, USA
[2]University of Colorado, Boulder, CO 80309, USA

Cross-beam energy transfer (CBET) is a laser-plasma interaction where power is transferred between two intersecting lasers in a plasma environment. The amount of power transfer between the beams is determined by the plasma response to the ponderomotive force at the difference in frequency, $\Delta\omega$, and wavevector, Δk, between the two lasers. We have derived the CBET transfer between lasers in a magnetized plasma using Vlasov-Maxwell theory with a background magnetic field. Magnetization adds significantly greater complexity to the CBET physics. Several findings include the ability of cross-polarized lasers to transfer power, the reduction of the transfer rate between parallel-polarized lasers and significant power transfer over a broad range of ($\Delta\omega$, Δk) due to nonlinear ion cyclotron Landau damping. We also see evidence of ion Bernstein, ion acoustic and fast magnetosonic plasma modes in the power transfer rate. CBET plays an important role in determining the implosion shape and drive coupling in both indirect and direct drive ignition designs. We discuss potential impacts of these results on inertial confinement fusion ignition designs relevant to cases with self-generated or externally applied magnetic fields.

*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 by the LLNL-LDRD program under Project Number 23-ERD-025.

Status of the magnetized cross beam energy transfer (MagCBET) campaign *

Bradley B. Pollock[1], Luis S. Leal[1], John D. Moody[1], David J. Strozzi[1], and Yuan Shi[2, †]
1. Lawrence Livermore National Laboratory
7000 East Ave, Livermore, CA 94550
2. University of Colorado Boulder
2000 Colorado Ave, Boulder, CO 80309
† Yuan.Shi@colorado.edu

Laser-produced plasmas are often spontaneously magnetized. Additionally, external magnetic fields are imposed in magneto-inertial fusion experiments to achieve more robust and higher yields. To understand magnetization effects on cross beam energy transfer (CBET), which controls the coupling and symmetry of laser-driven implosions, we conduct MagCBET campaigns at OMEGA. In this presentation, we will summarize experimental data from the past two years and discuss related simulations for two configurations. (1) In the gas-MIFEDS configuration, a laser-heated gas jet provides a plasma target, which is magnetized using a pair of MIFEDS coils. After heater beams are turned off, we use a single OMEGA-60 beam as a CBET pump, and the wavelength tunable TOP9 beam as a CBET probe. We use Transmitted Beam Diagnostics (TBD) to measure CBET as a function of wavelength detuning. Our data show that magnetization reduces CBET at fixed laser drives. The data is partly explained by an increase of plasma temperature when magnetized, which is captured by radiation-magnetohydrodynamics (rad-MHD) simulations. Additionally, particle-in-cell (PIC) simulations reveal enhanced ion-acoustic wave damping due to magnetization at a fixed plasma temperature. (2) In the foil-coil geometry, a laser driven coil produces a magnetic field, and a laser heated foil produces a plasma plume. In this configuration, two OMEGA-60 beams of equal wavelength are used as the CBET pump and probe. Resonance is achieved by unequal Doppler shifts of the two lasers in the plasma flow. Preliminary data suggests that magnetized jets are formed, in agreement with rad-MHD simulations. Additionally, CBET is measured in the magnetized jet using Full Aperture Backscattering Stations (FABS) as transmitted beam diagnostics for the opposing beams. The coil-foil configuration provides a stronger magnetic field, which PIC simulations suggest that magnetized resonances, away from the usual acoustic resonance, may mediate additional CBET over a broader bandwidth.

* This work is performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 and by the LLNL-LDRD program under Project Number 23-ERD-025.

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Simulations of LPI-generated hot electrons with an applied external magnetic field

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The application of an external magnetic field can modify the laser-plasma instability growth. Particularly, it has been inferred that the gyrating electrons transport energy away from the instabilities when they travel parallel to the growing field, weakening the electron plasma waves (EPWs) through Landau damping and overall reducing the instabilities' growth[1]. Moreover, the applied Lorentz force can confine the gyrating high energy ("hot") electrons in a limited region of space, dictated by the magnetic field's strength.

This can have several applications, such as a reduction in hot electron preheat in the case a magnetic field is applied to a laser-driven implosion[2] and to inertial confinement fusion (ICF), but also to the study of magnetized plasma jets.

To investigate these effects, we performed 2D simulations using the hybrid code Laser Plasma Simulation Environment (LPSE)[3] of Stimulated Raman Scattering (SRS), Two-Plasmon Decay (TPD), Langmuir Decay Instability (LDI) and Langmuir Wave collapse (LW collapse). We performed a scan of electron temperature and density scale length, at different magnetic field strength (from an unmagnetized case up to a 60 T field). We report a decrease in SRS, TPD and LDI activity in the nominal magnetized case (30 T) compared to the unmagnetized one. This is due to the increased Landau damping from the resonant energy exchange with the electrons. Moreover, the increase in LW collapse activity, coupled with the Fourier spectrum of the EPW field, suggests that the low-k modes are present in greater proportion, generating a greater number of plasma density depressions and increasing turbulence. The study of particle trajectories shows an increase in Larmor radius and overall acquired energy for the thermal ("bulk") plasma, and a similar increase for the hot electrons as well. A scan of the velocity distribution function (VDF) depending on the applied magnetic field confirm these results. Moreover, we observe a reduction in collected hot electrons for stronger magnetic fields, showing an increase in hot electron confinement.

For these reasons, we ask for an oral presentation to share these results with the scientific community.

---

[1] Winjum, B. J., F. S. Tsung, and W. B. Mori. "Mitigation of stimulated Raman scattering in the kinetic regime by external magnetic fields." *Physical Review E* 98.4 (2018): 043208.

[2] Bailly-Grandvaux, M., et al. "Impact of strong magnetization in cylindrical plasma implosions with applied B-field measured via x-ray emission spectroscopy." *Physical Review Research* 6.1 (2024): L012018.

[3] Follett, R. K., et al. "Thresholds of absolute instabilities driven by a broadband laser." *Physics of Plasmas* 26.6 (2019).

An early look at laser plasma interaction at a next generation indirectly driven inertial confinement fusion facility*

T. Chapman, D. E. Hinkel, A. L. Kritcher, J.-M. Di Nicola, and N. Lemos
Lawrence Livermore National Laboratory
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chapman29@llnl.gov

Design work is underway to identify the laser requirements and target properties to achieve 100s of MJ yields at a next generation of laser facility for indirectly driven inertial confinement fusion (ICF). The energy assumed to be delivered to the target by the laser in these designs is approximately 10 MJ. Avoiding excessive drive loss to laser plasma interactions (LPIs) is a central consideration in both laser and target design. Achieving the needed implosion symmetry will require controlling deleterious LPI and likely also require reproducing the capability to deliberately redistribute drive power via crossed beam energy transfer that is currently available at the National Ignition Facility (NIF).

The hohlraum size relative to those currently fielded at the NIF is expected to increase by a factor of 1.6-2. Currently, estimates are that to accommodate the yield and debris of such targets, the chamber radius will need to increase by a factor of approximately 2.5 relative to the NIF. The cross-section of optical components likely cannot be scaled similarly due to cost and uncertainty of manufacturing feasibility. As a result, the *f*-number of the individual laser beams will increase by a factor of 2 relative to that of the NIF (f~20 $\rightarrow$ f~40). To our knowledge, LPI with f~40 has not been tested experimentally in regimes relevant to ICF.

In this work, the impact on LPI of increasing the *f*-number (notably, laser speckles have a length proportional to f^2) and the target scale length is explored using simulations (pF3D). Given the nearly unbounded parameter space, we focus here on targets hydroscaled from current igniting designs at the NIF. Future work will explore other, perhaps significantly different, designs. We discuss experiments scheduled for FY26 that will sub-aperture NIF beams to assess the impact of f~40 laser speckles on LPI in current igniting designs.

*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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Two-dimensional Vlasov-Fokker-Planck modeling of electron transport and magnetic field generation for hohlraums*

M. Sherlock[1], A. R. Bell[2], C. Crilly[3], P. Moloney[3], J. Chittenden[3] and J. Bissell[4]
[1]Lawrence Livermore National Laboratory
5000 East Ave
Livermore, California 94551
Sherlock3@llnl.gov
[2]Rutherford Appleton Laboratory and University of Oxford, UK
[3]Imperial College London, UK
[4]University of York, UK

We have coupled a two-dimensional electron Vlasov-Fokker-Planck model with the Chimera radiation-hydrodynamics code, with the aim of understanding thermal transport and magnetic field generation in high-Z hohlraums. Simulations of wall heating, with the associated bubble expansion and transport into the hohlraum gas, reveal a number of differences when compared to standard simulations with flux-limited Braginskii transport. We find that the magnetic field generation is dominated by pressure anisotropies, leading to a highly-magnetized, turbulent shocked-gas region and magnetic filaments in the bubble and gas which cause nonuniformities in the temperature, density and heat-flow. Kinetic dispersion relations that attempt to describe the growth rate and wavelength of the observed magnetic instabilities in terms of the collisional-Weibel and magnetothermal mechanisms will be presented. Other aspects of the interaction, such as the suppression of the heat-flux, Nernst effect and Biermann battery will be discussed.

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

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Optimal bandwidth spectra for minimizing Two Plasmon Decay

A. S. Joglekar[*†], R. K. Follett[†], D. H. Froula[†], J. P. Palastro[†]
Ergodic LLC
Seattle, WA, 98103
archis@ergodic.io
[†]Laboratory for Laser Energetics, University of Rochester
Rochester, NY 14623

Previous work has shown that broadband lasers can mitigate laser plasma instabilities. Follett et. al considered various amplitude shapes (e.g. uniform, gaussian) and random phases, and showed that the mitigation can be predicted by determining the coherence time and that it is invariant with respect to the amplitude shape given the same coherence time. In this work, we explore whether optimal spectra (in both amplitude and phase) exist, what their characteristics are, and how well or poorly they mitigate the two plasmon instability in comparison to the previous approaches (e.g. uniform amplitude and random phase). We will discuss optimal spectra for realistic plasma parameters. The parameter space that is explored is given by –

$$2 \text{ keV} < T_e < 4 \text{ keV} \parallel 200 \text{ um} < L_n < 600 \text{ um} \parallel 10^{14} \text{ W/cm}^2 < I < 10^{15} \text{ W/cm}^2$$

To do this, we need to perform optimization of the slowly varying enveloped wave partial differential equations in a high-dimensional (O(100)) parameter space. This requires many iterations using gradient descent. We rewrite the LPSE solvers in a differentiable framework to make them amenable to performing gradient descent and to running on GPUs. Each of these are key enabling technologies for performing optimization of multi-dimensional PDEs in a high-dimensional parameter space.

Impact of smoothing by spectral dispersion on laser-plasma interactions in NIF indirect-drive experiments.

H.J. Meyer*, A. Oudin, M. Erickson, N. Lemos, A.J. Kemp, J.M. Di Nicola, O. Landen, T. Chapman, J.S. Ross, J.D. Moody and P. Michel
Lawrence Livermore National Laboratory
7000 East Ave
Livermore, CA 94550
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A future higher yield laser indirect drive inertial confinement fusion (ICF) facility will have increased vulnerability to laser plasma instabilities (LPI) compared to the National Ignition Facility (NIF). This hypothetical system will have substantially more laser energy and use larger scale hohlraum targets; this might result in increased stimulated Brillouin backscattering (SBS), posing a significant risk to the system's optics and target coupling efficiency. One proposed method of mitigating SBS is to increase the laser bandwidth through smoothing by spectra dispersion (SSD). Even though the achievable bandwidth remains much smaller than the instability growth rate, it is still expected to mitigate SBS in the weakly damped regime by making the speckles' lifetime shorter than the convective saturation time of SBS [L. Divol, PRL 2007].

An experimental campaign was conducted at NIF where the SSD bandwidth was increased from 45 to 118 GHz (the highest ever fielded at NIF) to see how the backscatter as measured by FABS and the DrDs changed within a 1.1 MJ Au Hohlraum. The expectation was that this would decrease SBS on the outer 50° cones by a factor of 4-10. However, experimental results showed no clear evidence of SBS mitigation outside the shot-to-shot reproducibility error bar. New pF3D simulations capture this result, suggesting that beam refraction near the laser entrance hole (LEH) causes significant localized intensification of the laser beam within the gold wall plasma, pushing SBS into a regime where 118 GHz of SSD is not able to act as a mitigator. These simulations suggest that this platform would have needed closer to 300 GHz of bandwidth in order to see the originally expected result. This platform is modest compared to what could be expected on a future facility or even NIF's HyE platform, both of which would require an even larger bandwidth for SBS mitigation. Such a high bandwidth would be increasingly taxing on the laser system (FM-AM and 3w conversion) and could possibility eliminate the ability to use CBET for symmetry control.

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Mitigation study of laser plasma interactions with broadband lasers*

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Laser-plasma instabilities (LPI), such as cross-beam energy transfer (CBET), stimulated Raman scattering (SRS), and two plasmon decay (TPD), play a critical role in direct-drive inertial confinement fusion. These instabilities can inhibit the coupling of laser energy to the target plasma by redirecting the laser light into unwanted directions and prematurely heat the imploding fuel by generating supra thermal electrons. To date, the most promising mitigation strategy for these instabilities involves the use of powerful lasers with broad spectrum bandwidths. Here, we will present the preliminary results of LPI mitigation study performed at the company Focused Energy.

* The authors gratefully acknowledge the Gauss Centre for Supercomputing e.V. (www.gauss-centre.eu) for funding this project by providing computing time on the GCS Supercomputer JUPITER | JUWELS at Jülich Supercomputing Centre (JSC).This work conducted under the auspices…., if you have any. If not, then delete this line, and the asterisk at end of title.

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Gaussian Laser Beam Filamentation Influenced by Additional Smoothed Laser Beams

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High-intensity laser propagation through plasmas is often limited by laser filamentation which can inhibit clean beam transmission, reduce the efficacy of laser-target coupling, and drive additional laser-plasma instabilities. Filamentation is typically considered a single-beam instability that arises due to non-uniformities in the laser intensity, phase front, or plasma density. However, we present experimental and simulation results showing the filamentation and the resulting beam spray of a Gaussian f/50 beam is enhanced by additional spatially and temporally smoothed laser beams. Our experiment utilizes the joint operation of the OMEGA 60 and OMEGA EP laser systems at the University of Rochester's Laboratory for Laser Energetics. In the experiment, an apodized 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. A gas-jet target is ionized and heated by 500 ps 3ω heater beams which use distributed phase plates (DPP) and smoothing by spectral dispersion (SSD). The resulting plasma conditions are measured via spatially-resolved Thomson scattering while the spray of the filamented short-pulse beam is recorded with a transmitted beam diagnostic. Results show significant amounts of spray of the short-pulse beam when propagating through the plasma while heater beams are on which remains unmitigated when SSD is turned on. In contrast, beam spray is reduced when the short-pulse beam propagates through the plasma after the heater beams have turned off and while at the same plasma conditions. Supporting 2D LPSE simulations indicate density fluctuations driven by overlapped DPP beams lead to enhanced filamentation seed levels which SSD on the order of ~1 Å fails to mitigate.

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On the influence of optical smoothing technics on cross-beam energy transfer

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Optical smoothing of laser beams is widely used to better control laser propagation in inertial confinement fusion experiments[1] and usually combines the use of smoothing by spectral dispersion (SSD) with phase plates. On the one hand, phase plates spatial smoothing consists in breaking the laser beam into a broad beam made of small speckle structures, producing spatial incoherence. Smoothing by spectral dispersion, on the other hand, induces a periodic displacement of these speckles by phase modulating and dispersing the signal. These techniques are used in many high energy laser facilities including the National Ignition Facility and the Laser Mégajoule. It has been shown numerically[2,3] that Cross Beam Energy Transfer (CBET) can be greatly reduced by taking into account the realistic speckle structure of the beams, thus possibly affecting the symmetrical compression of the fuel capsule in inertial fusion experiments[4]. In a recent paper, we proved analytically that spatial incoherence (in particular beam aperture) effectively perturbs CBET when it is induced by a wavelength shift[5].

In this work, we generalize the previous model by including smoothing by spectral dispersion and analytically address the SSD bandwidth influence on CBET. This model, validated using the Smilei PIC[6] code, shows the significant influence of the beam dispersion and how the lack of synchronization of the phase modulation between the two laser chains may affect CBET.

We finally apply our model to a hohlraum plasma and demonstrate the need to improve the CBET[7,8] modeling in radiative hydrodynamics codes[9].

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LaserNetUS: the first five years of scientific discovery

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LaserNetUS was launched in 2018, with a mission to advance and promote intense ultrafast laser science and applications. Since its inception, the network has transformed the landscape of high-power and high-intensity laser research, and it has grown into a community of over 1300 users. Additionally, it promotes worldwide collaborations and provides scientists, students, and underrepresented communities with broad access to unique facilities and enabling technologies. LaserNetUS has gone through 6 cycles of open calls for proposals, and over 70 unique experiments have been successfully executed across the network. Following on the success of LaserNetUS, the DPP community has launched new similar networks (MagNetUS, ZNet) to stimulate scientific discovery.

This plenary talk will present the scientific achievements across the LaserNetUS network and its 13 facilities over the first five years of operation. The breadth of laser parameters in pulse energy (from sub-Joule to a few kilojoules), pulse duration (from about 10 femtoseconds to 10s of nanoseconds) and repetition rate (up to 10 Hz) have enabled unique discoveries and applications in plasma-based particle acceleration, high energy density science, fusion energy, magnetic field generation, and plasma diagnostics. The talk will further present perspectives on the future of the network and how it can continue to stimulate high impact science in plasma physics, as well as in other scientific disciplines, medicine or industry.

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Parameter scan of stimulated Raman scattering in a magnetic field*

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There is growing experimental evidence that stimulated Raman scattering is altered in the presence of a weak magnetic field ($\omega_c/\omega_p << 1$). However, both increased and decreased levels of SRS reflectivity have been observed. We show particle-in-cell simulations of nonlinear EPWs and SRS across a wide range of laser and plasma parameters, scanning from the fluid to the kinetic regime and from strongly damped to weakly damped SRS. This parameter scan offers a window into the evolution of SRS in different regimes and the impact that can be had by altering its daughter waves damping and frequency, their wave envelope, and their further decay via secondary instabilities. We demonstrate how the increase or decrease of SRS reflectivity is dependent on the relationship between time and space scales of nonlinear wave evolution, resonant particle motion, and instability growth.

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The Effects of Coulomb Logarithm Model on Laser Energy Deposition into Materials*

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Accurate modeling of inverse bremsstrahlung absorption (IBA) is critical for simulating laser-plasma interactions (LPI), especially in inertial confinement fusion (ICF) applications. In this study, we evaluate multiple Coulomb logarithm models to quantify their impact on laser energy absorption into plasmas. Our primary findings show that models that include the laser frequency dependence (such as the Sommerfeld-Maue[1,2] and Oster[3] models) best capture the laser deposition into plasmas. The Sommerfeld-Maue model is an exact quantum-mechanical solution for bremsstrahlung emitted during electron-ion collisions, while the Oster model includes additional assumptions that results in a simpler and more computationally efficient form for the Coulomb log. We compare these models through xRAGE radiation-hydrodynamic simulations benchmarked against recent LPI experimental data[4]. Additionally, our models are validated against historical laser-to-X-ray coupling experiments[5]. This validation effort establishes a reliable foundation for incorporating these improved IBA models into fully integrated hohlraum/target simulations of high-yield shots performed at the National Ignition Facility.

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Particle-in-Cell Simulations of rescattering under IFE relevant conditions

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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 (λ2) 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 (under direct drive IFE conditions) and by inflationary stimulated Raman scattering (under indirect drive IFE conditions) and discuss the relevance of these simulations to future target designs. We will look at the saturation mechanism of this process by ion dynamics, either through the competition between SRS and SBS and through the generation of ion fluctuations which stops the growth of the plasma waves.

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Diagnosing burning plasmas at the National Ignition Facility via reaction-in-flight deuterium-tritium fusion neutron spectral measurements *

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In the pursuit of exceeding ignition at inertial confinement fusion (ICF) facilities, critical quantities to diagnose include α-heat deposition, that can improve, and impurities mixed into the plasma, that can limit performance. In high-density, highly-collisional ICF burning plasmas there is a significant probability that deuterium-tritium (DT) fusion products, 14 MeV neutrons and 3.5 MeV α particles, will collide with and transfer energy to surrounding DT fuel ions. These up-scattered ions can then undergo fusion while in-flight and produce higher energy neutrons, up to 30 MeV. The resulting reaction-in-flight (RIF) neutrons are uniquely identified in the measured neutron energy spectrum.[1] The magnitude and shape of this spectral feature can inform on the stopping-power of the DT plasma and is therefore directly proportional to α-heat deposition. In addition, the RIF spectrum can be correlated to mix into the burning fuel, relevant for high-Z shell and other emerging target platforms at ICF facilities.[2] The requirements for the neutron time-of-flight diagnostics at the National Ignition Facility (NIF) to obtain these small signals, ~10^{-5} times the primary DT neutron peak, are discussed. RIF spectra from several Gain > 1 implosions are contrasted against those with marginal burn. And comparisons of experimental data to computational models are made.

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LLNL-ABS-2003889

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X-ray generation in foam filled hohlraums via non-thermal electrons accelerated by laser plasma interactions*

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X-ray sources in the 20-50 keV range are challenging to generate at the high fluences required for extreme radiation material testing and related applications. Current methods rely on laser heating of high-Z nanowire foams to achieve extreme plasma temperatures. We are exploring an alternative approach using non-thermal electrons generated by laser-plasma interactions, such as Stimulated Raman Scattering (SRS) and Two-Plasmon Decay (TPD). These non-thermal electrons produce bremsstrahlung radiation when interacting with high-Z converters, such as gold hohlraums. Foam filled hohlraum targets have been developed, allowing tunable fill densities and gradients to optimize laser-plasma interactions and control the resulting x-ray spectra.
Results from previous campaigns at the National Ignition Facility will be discussed with updated model fits of hot electron and x-ray emission and SRS backscatter data. Results from new experiments on the Omega laser system will also be shown. New experiments on the OMEGA laser system focus on understanding laser-plasma interactions and hard x-ray generation. Diagnostics, including an SRS streak camera and TPD imager, are used to correlate laser-plasma interactions with hard x-ray signals and other x-ray diagnostics. The hohlraums are filled with CH foam at densities of 4.0 mg/cc and 7.5 mg/cc, corresponding to 0.15 and 0.25 of the laser's critical density, respectively, to disentangle the contributions of SRS and TPD to hard x-ray generation. We then compare experimental results with HYDRA simulations post-processed using FLIP. These simulations provide insights into SRS gain, spectra, and thermal emissions from the hohlraums. This work aims to advance our understanding of non-thermal electron generation and optimize hard x-ray sources for future applications.

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Neutron diagnostics and neutron generation with Z-Petawatt*

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We will present diagnostic characterizations and initial experiments towards establishing a laser driven neutron source for neutron-detection instruments. With an on-target intensity of approximately 10^{20} W/cm², structured and non-structured targets made from deuterated polymers can be driven to energy densities that are sufficient for the generation of 2.45 MeV fusion neutrons. An array of Photomultipliers with scintillators, X-ray sensitive diodes, particle detectors, and activation samples can be used to cross-calibrate individual instruments and develop the neutron source itself.

Low-energy (2-4 J) short-pulse laser shots are used to generate a quasi 'delta-function' peak for the determination of the impulse response function (IRF) of a detector, full system laser shots with up to 200 J will be used to generate a neutron source with at least 10^7 neutrons per shot. Preparatory experiments help to determine the IRF of neutron detectors which are used on Sandia's Z-Machine and to characterize scatter- and skyshine-background of the target area.

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An improved extended hydrodynamics model for interpenetrating plasmas

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Kinetic effects, including non-Maxwellian particle velocity distributions or flow interpenetration, can come into play in the hot thermonuclear fuel inside an Inertial Confinement Fusion (ICF) capsule[1] or in the low-density plasma in an indirect drive ICF hohlraum[2]. This motivates the development of extended hydrodynamics codes taking those effects into account.

In this work, the moment-based extended hydrodynamics model described previously[3] has been improved using a three-node quadrature-based closure[4]. The latter involves moments of the velocity distribution of order up to four. The model is now shown to be strictly hyperbolic, allowing arbitrarily large deviations from thermodynamic equilibrium. A numerical implementation of it in plane 1-D geometry, using a central-upwind scheme[5,6] preserving moment realizability, is presented. Numerical tests of the model are discussed, including plasma interpenetration at high velocity and the structure of a high-Mach number plasma shock front[7,8].

Extension of the model to spherical 1-D geometry is under way, aiming at better rendering strongly kinetic ICF implosions[1] while avoiding costly kinetic simulations[9].

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Using Direct Drive Data to Validate Los Alamos National Laboratory's xRage Common Model Framework*

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Direct drive target designs provide the greatest opportunity for the types of symmetric, directionally independent targets necessary for future high repetition fusion facilities. Designing such targets with high fidelity and confidence is crucial to making inertial fusion energy (IFE) a viable path for green energy. Los Alamos National Laboratory's hydrodynamics code xRage is useful for simulating both symmetric and polar direct drive inertial confinement fusion target implosions like those being designed for IFE platforms. Using Los Alamos National Laboratory's xRage common model framework (CMF) as a starting point, we validate simulations against direct drive Omega and NIF data to ascertain the energetics of polar directly driven capsule implosions. The Omega experiments vary the beam-to-capsule ratios to test laser energy coupling while eliminating cross beam energy transfer. We simulate polar drive capsule implosions from experiments at the National Ignition Facility to test scaling of our polar drive modeling. X-ray self-emission radiography is used in both cases to extract the capsule radius as a function of time. This work is performed with the intention of building a robust basis in the CMF for future symmetric and polar direct drive target design for platforms on OMEGA, NIF, and future high laser energy systems, such as Xcimer Energy's planned 10MJ facility. This document has been provided release under the identifier LA-UR-00-00000.

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Does the WKB Approximation for the B-SRS Turning Points Describe a Spatio-Spectrally Discrete B-SRS Instability Spectrum in a Density Gradient Plasma?

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The Wentzel–Kramers–Brillouin (WKB) approximation predicts the amplification region of the weakly damped Backward-Stimulated Raman Scattering (B-SRS) instability in an inhomogeneous plasma. We are investigating if these amplification regions can significantly overlap with one another to give a continuous backscattered SRS spectrum or whether they act independently to produce discreet peaks in the Raman backscattered light [1], [2].

To probe this instability, we use a short pulse 2 ps FWHM (~60 laser cycles) CO_2 laser with a normalized vector potential of a_0 ranging from 0.5 to 1.0. We diagnose the spectral amplitude electromagnetic (e.m.) daughter wave by a custom made ZnSe long-wavelength IR prism spectrometer that covers the spectral range from 10 – 16 µm with spectral resolution of $\Delta\lambda \leq 100\ nm$. The energy and momentum matching condions, $\omega_o = \omega_s + \omega_{EPW}$ and $\boldsymbol{k_o} = \boldsymbol{k_s} + \boldsymbol{k_{EPW}}$ of B-SRS, describe how a laser driver, $(\omega_o, \boldsymbol{k_o})$ scatters from collective fluctuations in plasma at $(\omega_{EPW}, \boldsymbol{k_{EPW}})$ with an electromagnetic noise source of $(\omega_s, \boldsymbol{k_s})$. This e.m. noise source beats with the pump radiation, increasing the amplitude of the EPW via the ponderomotive force resulting in the EPW re-scatter e.m. radiation at ω_s, the frequency of e.m. noise, growing the e.m. daughter wave via a highly efficient feedback loop.

As the B-SRS instability grows in a plasma with a density gradient, it locks onto a density resonance, z_m, and the two daughter waves are amplified over a small region of space, as described by the WKB approximation. The two WKB turning points for the exponentially growing solution to the parabolic cylindrical equation are described by $\pm z_T = \pm\gamma_o/\kappa'\sqrt{v_{g,s}v_{g,EPW}}$, where γ_o is the temporal growth rate, κ' is the derivative of the WKB dephasing term $\kappa(z) = k_{EPW}(z) - k_o(z) - k_-(z)$, and $v_{g,s}$ and $v_{g,EPW}$ are the group velocities of the scattered and plasma waves [2]. Using fully self-consistent PIC simulations we observe that the amplitude of the plasma wave grows backwards from a discrete resonant point on a density ramp and the termination of this process is determined by the phase mismatch between this driven EPW, $k_{EPW}(z) \cong k_o(z_m) + k_-(z_m)$, and the plasma density at which this resonant grow from. Contrary to the common understanding, we find that an infinite number of resonances do not amplify once the intensity threshold is exceeded. Instead there are localized regions of amplification which can be described by the W.K.B. turning points. These findings demonstrate how discretized process of B-SRS where the temporal evolution of neighboring B-SRS amplification regions influence how and at what frequencies B-SRS is amplified. In this talk experimental results will be presented and compared with Rosenbluth's formulation of B-SRS in a density gradient plasma.

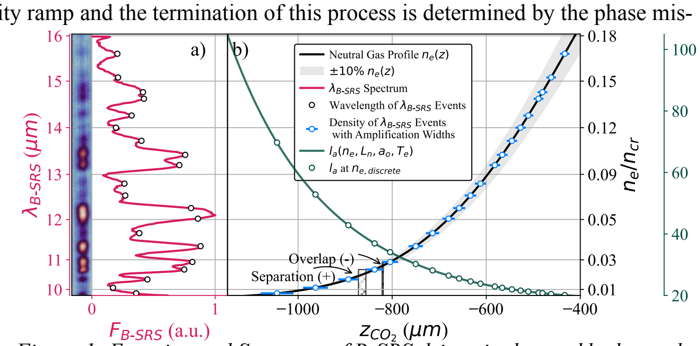

Figure 1: Experimental Spectrum of B-SRS driven in the weakly damped re

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53rd Annual Anomalous Absorption Conference
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Modeling stimulated Brillouin backscatter from the inner laser cones during indirect drive inertial confinement fusion experiments at the National Ignition Facility*

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We report progress modeling stimulated Brillouin scatter (SBS) at the National Ignition Facility (NIF). For indirect-drive, ignition-relevant hohlraum experiments, backward SBS light is a longstanding concern due to its potential for damaging laser optics as well as affecting the symmetry of the x-ray field that drives capsule implosions. To model SBS, our current approach is to use plasma maps from hydrodynamics simulations of the hohlraum to run backscatter simulations of NIF quads in the paraxial approximation with the code pF3D [Berger et al, POP26 (2019)]. For the inner cone quads, in designs that utilize significant wavelength detuning (i.e., those that use crossbeam energy transfer to control implosion symmetry), this approach typically over-estimates both peak power and duration of SBS measured in experiments. In this work we discuss how multi-species hydrodynamics simulations can lead to better agreement with experiments through changes to the simulated plasma conditions and resulting SBS growth rates. Specifically, we discuss SBS reflectivity in the 23- and 30-degree inner cone quads, compare simulated spectra to FABS measured ones and discuss how the time history of the backscattered light is related to the absorption / refraction of the incoming light off density features in the hohlraum plasma.

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Assessment of the Cross-Beam Energy Transfer (CBET) Risk for Polar Direct-Drive Wetted-Foam Designs*

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The polar direct-drive wetted-foam concept[1] is a promising design for achieving high-gain in inertial confinement fusion (ICF). The baseline target is composed of a spherical shell of 3D-printed (2pp) lattice that is wetted with liquid deuterium-tritium (DT) fuel, and surrounds a central DT gas region. A thin layer of CH typically coats the exterior of the target, and prevents leakage of the fuel. Such designs are thought to be advantageous for a variety of reasons, including high laser-target coupling, and good hydrodynamic efficiency.

One important aspect of the PDD-WF concept is that for much of the pulse, the laser will be ablating the wetted-foam, in contrast to the CH ablator typically used for conventional direct-drive targets. It is therefore important to understand the susceptibility of this ablator material to laser-plasma instabilities (LPI).

In this presentation, we discuss the risk posed by cross-beam energy transfer (CBET) to PDD-WF designs proposed for the National Ignition Facility. We investigate this via a combination of radiation hydrodynamics modelling, laser ray-trace calculations, and theoretical considerations. We find that ablation of wetted-foam leads generally to increased CBET losses relative to CH, and discuss the reasons for this. Finally, we consider possible mitigation strategies for CBET.

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53rd Annual Anomalous Absorption Conference
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Backscatter measurements of laser-plasma interactions relevant to an upgraded National Ignition Facility laser system*

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A proposed laser upgrade aims to achieve an enhanced yield capability (EYC) at the National Ignition Facility (NIF), enabling neutron yields to surpass the current accessible regime. To guide the design direction and determine facility requirements, an experimental campaign was developed to investigate laser-plasma interaction (LPI) within a 2.6+ MJ laser parameter space. Utilizing the increased energy of the upgraded NIF laser will require a larger hohlraum and capsule size compared to current ignition designs. However, these changes may lead to higher levels of LPI, which could negatively impact performance. To study LPI relevant to the upgraded laser, a 1.09x hydroscale of the current Hybrid-E platform was selected as the experimental design. Cross beam energy transfer (CBET) serves as a critical tool for tuning implosion symmetry. In this campaign, the wavelength detuning ($\Delta\lambda$) between the outer and inner laser cones was incrementally increased to investigate how LPI scales with rising inner cone power. This presentation will share results from the first four experiments conducted during FY24. We will discuss how backscatter LPI scales with $\Delta\lambda$, gold bubble growth, shock velocities, and implosion symmetry.

* *This work was performed under the auspices of U.S. DOE by Lawrence Livermore National Laboratory (LLNL) under Contract DE-AC52-07NA27344*

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High-yield implosions using DT wetted foam for inertial fusion energy (IF

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IFE applications require high repetition rates, and capsules utilizing DT wetted foams offer an advantage over those using a DT ice layer, as the foam does not require a prolonged duration for cryogenic layering. However, wetted foam can lead to significant yield degradation[1] due to several critical issues. (1) The C and O present in 3-D printed foams created by the 2PP process, or Si and O in chemically produced SiO_2 foams, absorb hard x-rays, which can penetrate conventional ablators, e.g., high-density carbon (HDC), Be, or CH. These x-rays preheat the foam, raise the adiabat, and reduce the areal density (ρR). The rate of preheating escalates with foam density. (2) There is additional radiation loss from the foam during the burn phase. (3) The inert mass of the foam in DT fuel reduces yield. (4) The turbulence created by shocks traversing the irregular foam structures can lead to under-compression.[2]

To evaluate the performance of DT wetted-foam implosions, we use an HDC capsule with an outer radius (OR) of 1189 μm, driven by an Au-lined DU hohlraum.[3] When the ice layer is replaced with a DT-wetted foam of 25 mg/cc density, the yield degradation is ∼55% in 1D simulation due to the x-ray preheating of the wetted foam. However, this degradation can be mitigated by ∼15% if an unlined-DU hohlraum is utilized to reduce the hard x-rays.[3] For a 50 mg/cc foam, ignition cannot be achieved. A larger Be capsule with an OR of 2340 μm absorbs 1.3 MJ of laser energy and achieves a 1D yield of 400 MJ. The extent of yield reduction varies between 20-80 %, depending on the O content, for a wetted foam at 25 mg/cc. Therefore, it is essential to develop methods to address the significant yield degradation.

The heavy ablator, known as the Pusher-Single Shell (PSS),[4,5] was designed with a high concentration of Mo to block hard x-rays effectively. It optimizes the trade-off between implosion velocity and ρR. The PSS features a Be ablator with a 20 at.% of Mo in the inner region. The concentration of Mo decreases toward the outer region to minimize the Rayleigh-Taylor instability. Calculations indicate that PSS has a high ignition margin, e.g., a 1500 μm OR PSS absorbing 490 kJ of laser energy has a yield of 40 MJ. The yield degradation associated with wetted foam is notably reduced — 15% (20%) for 25 mg/cc (50 mg/cc) foam density. The Mo blocks almost all the hard x-rays, resulting in minimal change to adiabat. For foam density less than 50 mg/cc, the under-compression caused by turbulence is likely negligible.[2]

*Worked performed under the auspices of the U.S. DOE by LLNL under contract DEAC52-07NA27344 and support SCW1835.

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Title: perusing through high yield experimental data at the National Ignition Facility

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We report on neutron and Xray data acquired on all recent high yield cryogenic DT layered implosion at the National Ignition Facility. We show that thermonuclear yield variations can change the interpretation of measurements (shape for example) and dynamics can be counter-intuitive at first glance (for instance the transition from stagnation to explosion during burn propagation). Some trends are explored using fully postprocessed generic 2D hydrodynamic simulations.

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The Impact of Fuel-Ablator Mix on Achieving Ignition in Inertial Confinement Fusion*

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This work investigates how small-scale defects in fuel capsules, common in pre-ignition experiments, impact thermonuclear yield and ignition. Using advanced analysis methods, we reconstruct in three dimensions the detailed temperature and density profiles from five deuterium-tritium layered (DT) experiments, each driven by 1.9 MJ of laser energy. The results show that a pre-ignition quality capsule experiences significant mixing, reducing thermonuclear yield by a factor of two. Radiation hydrodynamic simulations that match the measured mix profiles confirm that this mixing disrupts fuel compression and increases radiative energy losses, preventing ignition. Furthermore, scaling analyses indicate that capsules with such defects would require ~3 MJ of laser energy to achieve ignition, far exceeding current laser capabilities. These findings provide key insights into the physics of hydrodynamic mix in self-heated fusion plasmas and highlight the stringent capsule quality requirements for future inertial fusion designs targeting ignition and high energy gain.

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Reduced hohlraum gas fill density for improved inner beam propagation and implosion symmetry*

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To improve hohlraum efficiency relative to the high-performance, high-energy HYBRID-E campaign, we have conducted a multiple year experimental campaign on the National Ignition Facility (NIF). In this study, hohlraum losses are reduced by decreasing the laser entrance hole (LEH) diameter from 3.1 mm to 2.7 mm and the hohlraum diameter from 6.4 mm to 6.2 mm, resulting in extra x-ray flux for a given laser pulse. This more efficient hohlraum is a way to drive thicker shells, increase velocity, and/or reduce coast time to improve implosion performance beyond the current energy limits of the NIF. Such improvements in efficiency, however, come at the expense of symmetry control. The smaller LEH reduces x-ray losses from the polls, driving the implosion more effectively, but primarily in the oblate direction. Additionally, models and simulations suggest that the smaller diameter reduces the time before the gold bubble, launched by the outers (which deposit near the LEH), begins absorbing the inner beams (which deposit energy near the equator), leading to an oblate implosion. At 0.3 mg/cc fill density, experiments failed to achieve a round DT hotspot. Results from experiments at 3 different helium fill densities in the hohlraum will be shown: 0.15, 0.3, and 0.6 mg/cc. Simulations and simple models suggest that higher hohlraum fill density will effectively slow the gold bubble and filling from the ablator blow off, increasing the time for unimpeded propagation of the inner beams. In this presentation, we will show experimental results indicating that indeed the gold bubble velocity scales inversely with gas fill as expected, but that implosion symmetry scales in the opposite direction. In addition, we consider why this might occur and how we have tried to modify our simulations to predict this behavior.

* *This work was performed under the auspices of U.S. DOE by Lawrence Livermore National Laboratory (LLNL) under Contract DE-AC52-07NA27344*

Relating Metrology to Performance in Recent High Yield Implosions on the National Ignition Facility

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High yield indirectly-driven layered high density carbon capsule implosions on the National Ignition Facility exhibit sensitivity to x-ray drive asymmetry, fill tube geometry, and capsule quality[1,2]. The prediction of how metrologized defects (ablator nonconcentricity voids, surface pits, high-Z inclusions, microstructure, dopant banding, etc.) remains a challenge due to the small size (often sub-micron) of many of these features as well as the inherently three-dimensional interaction between asymmetries[3,4]. We have utilized the xRAGE radiation-hydrodynamics code[5,6] to provide pre-shot predictions of twelve HybridE[7] and SQ-n[8] high yield implosions on the National Ignition Facility as well as fourteen post-shot ensembles. In all calculations, we accurately model the geometry of the fill tube and capsule non-concentricity based on metrology. For post-shot calculations, we include flux asymmetry to account for available shape information from experimental imaging. Finally, in post-shots, we perform an ensemble of simulations with varied capsule quality to match the yield. When combined, the resulting simulation exhibit reasonable agreement with all experimental observables. We have compared the yield impact of quality from post-shot simulations to available metrology data and observe a strong correlation with the total volume of surface pits, a less significant correlation with high-Z inclusion observations, and the smallest correlation with void characterizations. We have used these correlations to generate a model for the impact of metrology on capsule performance and are now using it to predict the performance of individual capsules.

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Two-sided target designs for high standoff IFE implosions

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Xcimer Energy Inc., founded in 2021, is developing a next-generation fusion reactor based on laser-driven inertial confinement fusion (ICF). The company is advancing a novel, cost-effective, electron beam-pumped KrF laser system capable of delivering high-energy, microsecond-duration pulses compressed to ~10 ns using gas optics. The Phoenix prototype facility, now under construction, will amplify a seed beam by ~1,000× via Stimulated Brillouin Scattering (SBS) in a gas cell—preserving phase integrity while operating below optics damage thresholds. Backed by a $9 million DOE Milestone award and $100 million in Series A funding, Xcimer is also developing a fusion pilot plant based on the HY-LIFE concept, which uses a FLiBe liquid curtain to protect the chamber at 0.25–1 Hz repetition rates. This architecture is inherently compatible with two-sided target irradiation, simplifying the design of the liquid jet system.

Xcimer's target design program is focused on concepts optimized for this two-sided geometry. A recently published hybrid-drive baseline—developed in collaboration with the University of Rochester, Los Alamos National Laboratory, Lawrence Livermore National Laboratory, and General Atomics—uses a hohlraum-generated x-ray first shock for imprint mitigation, followed by direct-drive compression to enhance energy coupling[1]. This hybrid approach also creates a plasma atmosphere that enables equatorial laser absorption, improving implosion symmetry and smoothing out high modes from laser beam imprinting. Additionally, the system's beam zooming capability allows dynamic adjustment of the focal spot, opening new pathways for design innovation. This talk will present Xcimer's progress and roadmap for advancing two-sided target designs, including preconceptual hohlraum development, symmetry risk mitigation strategies, setting performance requirements for a wall-plug breakeven demonstration facility, scaling the target supply chain to IFE repetition rates, and deploying an initial target shooter to quantify and de-risk laser-plasma interactions.

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A common model framework for advancing physics models in radiation hydrodynamic codes for inertial fusion energy

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The complex Multiphysics multiscale regime of high energy density physics proves to be a challenge for radiation hydrodynamic simulation tools. While these tools do a good job modeling experiments, non-physical choices or calibration parameters play a role in matching simulations with experimental data. Often, the simulation of experiments covers a single configuration or a small set which all have similar attributes with regard to experimental parameters. This means the physics models are not validated such that they can be used to extrapolate to new design spaces for experiments. Over the past decade, LANL developed a common modeling framework to enable modeling larger sets of data using a common set of physics choices. While the choices still contain some non-physical parameters, matching a larger set of data across a larger parameter space help increase the robustness of the models. This process can also be used to identify models that are not broadly applicable such that new models can become a focus of development. Over the past six months, LANL implemented the common modeling for capsule implosions. This presentation will focus on the nuts and bolts of the common modeling framework for inertial fusion energy and its use in increasing the robustness of our modeling with the xRage radiation hydrodynamics code.

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Modeling for a 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 (PDD-WF) concept[1] that employ advanced fabrication techniques. To this end, we have designed and performed experiments in a simplified planar configuration using the OMEGA cryo-platform which drive a shock through the target by ablating a heterogeneous medium of two-photon-polymerization (2PP) 3D-printed lattice and liquid deuterium, where we aim to measure shock propagation speed and planarity relative to lattice morphology. A thin (~2 μm) high-density carbon front window and a laser pulse with a significant foot is used to ensure that the measured shock is the result of the ablation of the heterogeneous material and not just the propagation of a shock from a uniform ablator being driven through a heterogeneous medium. Warm analog targets where SiO2 aerogel replaces the liquid deuterium are employed to increase throughput and enable Thomson scattering measurements of the upstream mix in the blowoff region. Results of 2D and 3D xRAGE[2,3] simulations modeling the experimental setup for a range of lattice sizes will be presented for cold targets, showing the perturbation of the shock front generated by the 2PP lattice and how the shock front heals after breakout into the pure deuterium region. Results of warm target simulations will show the electron density variation expected in the blowoff and inform Thomson scattering measurements.

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Analysis of externally-driven hohlraums to support hybrid drive for the Xcimer IFE concept

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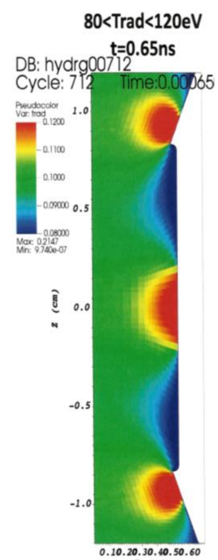
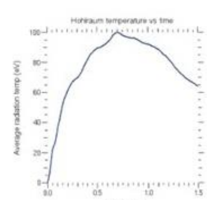
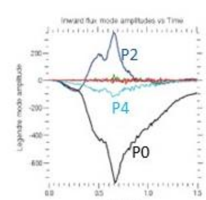
The method of radiatively heating a hohlraum using emission from laser-heated external surfaces has been mentioned previously[1], but not extensively explored. Here we look at techniques to improve the radiation temperature and x-ray drive symmetry of *externally-driven hohlraums* by modifying the shape and material properties of external areas where the laser source is intercepted to generate x-rays. We assume a 1ns laser pulse containing 200kJ of energy in the form of two collimated annular laser beams intercepting the area around each of the primary hohlraum's laser entrance holes (LEHs), consistent with the Xcimer ignition concept[2]. We find that the radiation temperature inside the primary hohlraum can be improved by tapering the laser interception area to form nozzle-like entrances to the hohlraum thereby allowing more of the Lambertian x-ray emission to enter and heat the primary hohlraum. Several conclusions from our study include the following:



1. Copper hohlraums perform as well as high-Z hohlraums for a 1ns, 100eV x-ray source.
2. Primary hohlraum radiation temperatures of 100eV can be achieved with 200kJ, 1ns laser drive.
3. X-ray drive modes above P4 do not seem to be of concern.
4. Both P2 and P4 modes can be tuned using the nozzle angle, hohlraum length and diameter.
5. Lensing of laser energy into the primary hohlraum occurs around 0.5 ns that causes the P2 radiation drive asymmetry to invert from the initial pole-hot P2 drive to equator-hot P2.
6. Adding a low-Z or high-Z ablative layer to the hohlraum entrance nozzles does not improve hohlraum performance.





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Designing a High Yield Polar Direct Drive Target with Los Alamos National Laboratory's xRage Common Model Framework *

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The future of inertial fusion energy (IFE) as a viable green energy source requires development in all areas from target manufacturing to power plant operation, thus simplifying the requirements and components will lead to the best chance of success. Consequently, we are evaluating polar laser direct drive of a spherically symmetric capsule at sufficiently large laser powers for maximal power production by neutron as a viable avenue for future high rep-rate experimental platforms. The work described here uses Los Alamos National Laboratory's (LANL) xRage radiation hydrodynamics simulations code to evaluate such designs via the LANL common model framework (CMF). The CMF is first used to evaluate existing experimental laser direct drive data to benchmark multibeam and direct drive simulations. Building on the validation work, we have designed preliminary polar direct drive capsules. Specifically, we are designing a polar direct drive target for the planned high power, high-energy two-sided illumination by Xcimer. For these designs we use a shaped, time dependent energy profile. This presentation will discuss the common modeling used to benchmark our simulation choices, and the progress towards simple spherical capsule designs for IFE. This document has been provided release under the identifier LA-UR-00-00000.

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Inverse Bremsstrahlung Absorption*

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Two experimental platforms have recently been developed to study inverse bremsstrahlung absorption. The first—an underdense gas-jet platform—proved most useful for establishing the proper high-frequency limit of the Coulomb logarithm and validating the Langdon effect.[1] In the process, we found that accounting for time-dependent (non-steady-state) ionization levels was essential,[2] and that there is a more accurate way to account for the impact of laser-heated electron distribution functions on absorption than Langdon's original absorption-reduction factor.[3,4] The second platform—a spherical-implosion platform diagnosed with the "beamlets" scattered-light detector—proved most useful for isolating the impact of screening on absorption at densities approaching the critical density.[5] Using an updated absorption model that combines insights from both platforms, we simulate the OMEGA-implosion database and find that nuclear bang times are well reproduced without any *ad hoc* multipliers.

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pF3D and the Journey to Exaflops*

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pF3D was originally written by Bert Still in the late 1990's. One of the goals for pF3D was to simulate LPI for a full NIF quad from the LEH to the hohlraum wall. That requires ~100 billion zones and would not fit on any computer in 2000. The Accelerated Strategic Computing Initiative (ASCI) was part of DOE's response to the end of underground testing. ASCI purchased a series of increasingly powerful computers over the years. The increase in memory and performance enabled us to run the desired simulations, but it took around a decade.

We ran a filamentation only simulation of a full NIF quad propagating several mm in 2003 using 1.9K cores on an 11 TFLOP/s Linux cluster. In 2008 we simulated a full NIF quad propagating from the LEH to the hohlraum wall (including SRS) using 22 billion zones and 192K IBM Blue Gene/L cores. In 2010 we ran a 110 billion zone simulation of 3 quads propagating thru 3 mm of plasma on 144K IBM Blue Gene/P cores.

In 2011 we ran a simulation of 3 quads propagating from the LEH to the hohlraum wall using 32k Intel Xeon cores on ASCI Cielo. Cielo had a peak performance of 1.11 PFLOPs and enough memory to easily fit 233 billion zones. Our Cielo CPU allocation allowed us to complete a job in about 6 weeks. The NIF point design usually changed before we could complete one of these runs! Our simulations did not increase in size after that point. We used 0.375 million IBM Blue Gene/Q cores on Sequoia to complete a 3-quad simulation in a reasonable time of one week.

Our next goal is to port pF3D to El Capitan GPUs which should enable us to complete several simulations in a week. El Capitan has a peak performance of 1.74 ExaFLOP/s, which is roughly 160k times faster than what we had in 2003. The modifications we are making for GPUs represent the first significant rewrite of physics functions since Bert Still wrote pF3D. We aren't changing the algorithms, but we must make our temporary arrays larger so that we pass enough work to a GPU to keep its thousands of cores busy. We report GPU speedups for individual pF3D functions and discuss our approach to completing the GPU port.

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Integrated radiation-magneto-hydrodynamic simulations of magnetized burning plasmas*

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Motivated by recent breakthroughs[1,2] in inertial confinement fusion (ICF), first achieving ignition conditions in National Ignition Facility (NIF) shot N210808 and then laser energy breakeven in N221204, modeling efforts have been begun to investigate the effect of imposed magnetic fields on integrated hohlraum simulations of igniting systems. Previous NIF experiments have shown fusion yield and hotspot temperature to increase in magnetized gas-filled capsules[3] in line with expected scalings[4]. In this work, we use the 2D radiation-magneto-hydrodynamics code LASNEX[5] with a Livermore ICF common model[6]. Simulations are tuned to closely approximate data from unmagnetized experiments. Investigated here is the effect of imposed axial fields up to 100 Tesla on the fusion output of historically high performing ICF shots, specifically N180128, N210808, and N221204. The main effect is increased hotspot temperature due to magnetic insulation. Namely, electron heat flow is constrained perpendicular to the magnetic field and alpha trajectories transition to gyro-orbits, enhancing energy deposition into the hotspot and cold fuel. However, magnetic fields must be fastidiously applied as secondary effects like magnetic pressure can resist or compromise the implosion. In addition, we investigate the impact of applied magnetic fields to future NIF designs, specifically an example Enhanced Yield Capability design with 3 MJ of laser energy as well as a high ρR, low implosion velocity "Pushered Single Shell" design. In conclusion, it is found that magnetization can increase ion temperature by 50% and neutron yield by >2. Specifically, we see notable yield enhancement of at least 50% with only a 5-10 T applied magnetic field for N221204, while a 65 T field on N210808 with drive symmetrization gives an 8x increase in yield. This is all without further design optimization to best take advantage of an applied B field, which suggests even greater promise for future designs tailored specifically towards magnetization.

* This work was conducted under the auspices of the U.S. Department of Energy by LLNL under contract DE-AC52-07NA27344 and Laboratory Directed Research and Development project 23-ERD-025.

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Achromatic Plasma Lenses

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Plasma-based optical elements have an intensity damage threshold significantly higher than their solid-state counterparts, making them ideal for manipulating intense, ultrafast light for laser wakefield acceleration and plasma-based radiation sources. Plasma lenses, in particular, offer additional flexibility in the focal geometry of high-power ultrashort pulse laser systems, where few conventional focusing optics may be available. Such plasma lenses can be created as either refractive plasma channels[1] or diffraction-based holographic zone plates[2]. Both forms exhibit chromatic aberration—plasma channels due to the wavelength-dependent plasma refractive index and plasma zone plates due to different wavelengths constructively interfering at different axial locations. When focusing broad bandwidth, ultrashort laser pulses, this aberration results in a wavelength-dependent spot size and focal length, which distorts the temporal pulse shape and reduces the peak intensity.

In this work, we show that the two kinds of plasma lenses can be sequentially combined to eliminate chromatic aberrations. Analytic theory and numerical solutions to the paraxial wave equation enable rapid optimization of the focusing power of each lens and their relative spacing. These calculations reveal that the tandem configuration can achieve achromatic focusing for a wide range of experimentally feasible parameters relevant to high-power ultrashort pulse lasers.

This work was partially supported by NNSA Grant DE-NA0004130, NSF Grant PHY-2308641, and the Lawrence Livermore National Laboratory LDRD program (24-ERD-001).

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Wave breaking in helical plasma waves*

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Wave breaking of electron plasma waves is a fundamental nonlinear process in plasma physics. It occurs when the wave has sufficient amplitude to accelerate electrons to velocities exceeding the phase velocity of the wave. Prior work has extensively studied this process for planar plasma waves, particularly in the context of laser-plasma interactions, where wave breaking plays a key role in electron trapping and acceleration. Here, we use three-dimensional particle-in-cell simulations to investigate the physics of wave breaking of electron plasma waves carrying orbital angular momentum. Preliminary results suggest that the amplitude limit of the wave and the electron distribution function depend on the helicity of the wave.

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Progress in kinetic modeling of hot electron production by two-plasmon decay with bandwidth and speckle*

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The mitigation of laser-plasma instabilities is a key consideration in the development of the next generation of laser drivers for inertial confinement fusion and high energy density physics experiments. Temporal structuring of laser pulses using frequency bandwidth can disrupt the coherent growth of instabilities and offers a path towards the mitigation of deleterious instability-driven effects such as hot electron preheat. While it has been demonstrated that broad frequency bandwidth increases the threshold intensity for the two-plasmon decay (TPD) instability, less is known about the behavior above threshold. We will present progress in modeling the saturation of TPD with both bandwidth and speckle using the particle-in-cell code WarpX. Preliminary results indicate that bandwidth may reduce – but is unlikely to fully mitigate – above-threshold hot electron production.

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Improving ICF Implosion Performance by Reducing its Residual Kinetic Energy*

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In recent 2.05 MJ and 2.2 MJ DT ignition experiments at the National Ignition Facility (NIF), implosion asymmetry is hypothesized to be significantly degrading implosion performance. The performance degradation due to implosion asymmetries can be correlated in part to residual kinetic energy remaining at peak compression[1]. Reducing RKE, in addition to mitigating sources of mix in the implosion, is important for increasing fuel burnup fraction and accessing higher fusion performance on the NIF. A reduction in RKE is inferred from 2D convergent ablator (2DConA) experiments that temporally resolve radiographs of the capsule trajectory and shape for the last ~1 ns before the implosion reaches minimum volume, covering the period of the implosion dynamics between peak implosion velocity and stagnation. Two 2DConA and one shock timing keyhole experiments have been completed at the NIF to assess whether RKE can be reduced by applying design modifications to the Hybrid-E platform[2]. These design changes include lengthening the hohlraum by 400 μm to allow for a re-pointing of the 50^{o} outer beams by 250 μm towards the laser entrance holes, and a lower inner beam cone fraction in the early part of the laser pulse. Moving the 50^{o} beams lowers the overlapping intensity of the outer (44° and 50°) beam spots on the hohlraum wall, which should delay the time-varying P2 flux asymmetry imparted on the capsule by the growth of gold plasma bubble occluding the inner beams. This modification also reduces the small positive P4 asymmetry observed in Hybrid-E implosions. In addition, using a pole-hot x-ray drive early in the laser pulse pre-compensates for time-varying P2 asymmetry that is unavoidable later in the pulse, resulting in a more uniform shell ρR distribution at stagnation. The recent experiments tested these modifications separately and show that the temporal variations in the capsule P2 asymmetry ("P2 swings") decrease significantly, while moving the hotspot shape more oblate, with shock timing data that matches simulations calibrated to similar Hybrid-E experiments. A final 2DConA experiment will recover a round hotspot shape, while keeping the P2 swings low. A DT layered fuel experiment will then be executed to show whether this reduction in the capsule P2 symmetry swings translates into improved fuel compression and potentially higher fusion yields.

* Work performed under the auspices of U.S. Department of Energy by LLNL under Contract DE-AC52-07NA27344

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Physics of direct-drive wetted foam ICF capsules*

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In this direct drive ICF concept, a liquid DT layer is supported by a low-density 3D printed CH lattice[1,2]. The foam-like 3D printed lattice shell is saturated with liquid DT and serves as both an efficient ablator and a dense fuel layer. The central DT vapor density is set by the cryogenic fielding temperature. This provides a technique for controlling the implosion convergence ratio[3] and increasing the robustness to instability growth[4]. The hot spot pressure required for self-heating is reduced if the hot spot radius is increased. With a reduced hot spot pressure requirement, the implosion velocity and fuel adiabat requirements are relaxed. The large, reduced pressure ignition-level hot spot requires increased energy, but this is made possible via the use of a large, low aspect ratio direct-drive capsule and a high efficiency wetted foam ablator.

Previous wetted foam ICF experiments[3-5] have shown that a mixed EOS must be used to accurately simulate the experimental implosion results. This is largely due to the fact that a DT+CH mixed EOS is less compressible than pure DT. An important additional feature of the wetted foam approach to high gain ICF involves the delay of burn propagation caused by the presence of CH in the dense DT fuel layer at the time of ignition. These two features combine to limit the carbon concentration in the fuel layer and, hence, the density of the CH foam lattice. Overall, we show that the 3D printed foam-like lattice used to support the cryogenic liquid DT layer should have a density < 20 mg/cm^3.

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Resolving anomalous ion temperatures on igniting shots at the National Ignition Facility using a gamma-based nToF*

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With the achievement of ignition and MJ yields at the National Ignition Facility (NIF), deuterium-tritium (DT) ion temperatures above 15 keV are routinely being measured by the suite of neutron time-of-flight (nToF) spectrometers. This is a new regime for Inertial Confinement Fusion (ICF) implosions, and understanding these measurements is crucial to evaluating performance and refining experimental designs to push to higher yields. Each NIF nToF has both scintillator-based[1] and Cherenkov-based[2] detectors, which measure the same neutron beams with different mechanisms and instrument responses. Apparent ion temperature is determined from Doppler broadening of the 14 MeV primary DT neutron peak. As yields at the NIF have increased, discrepancies in the ion temperatures from these two detection methods have grown: scintillator values are consistently higher than Cherenkov values, with differences up to 5 keV for the highest temperature implosions (T_{scin} = ~20 keV, T_{cher} = ~15 keV).

An extensive effort has been undertaken to address this diagnostic anomaly, with testing being performed both on-shot at NIF and externally at other neutron sources. A key step in resolving the discrepancy has come through the use of a novel, 3rd approach to nToF measurements: measuring the 4.4 MeV γ from ^{12}C(n, n'γ) in the scintillator[3]. This gamma-based nToF (g-nToF) has significant advantages in simplicity and speed, and high quality data has been obtained at two g-nToF test locations at the NIF thanks to the highly collimated neutron beams and significant shielding in the test setups. Ion temperatures from the g-nToFs agree well with the scintillator results on MJ yield shots, giving a high degree of confidence in these measurements. An overview of the g-nToF tests at the NIF will be given. Results from the Magnetic Recoil Spectrometer (MRS) also show agreement with the scintillator ion temperatures.

Testing is now focusing on the Cherenkov-based nToFs, to determine the cause of their artificially low ion temperatures. Results from this testing effort will be presented.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-ABS-2003769.

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Bow shock characteristics and ion heating in a plasma flowing across randomized laser beams.

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High-energy lasers interacting with flowing plasmas can induce a plasma response that results in beam bending and, through momentum conservation, slows down the plasma flow velocity [1]. When the incoming supersonic plasma flow slows to subsonic speeds, the speckled laser beams can generate a shock within the plasma [2,3]. We report on recent advancements in shock detection and measurement, focusing on properties such as density and ion temperature jumps, and shock propagation speed, using Thomson scattering. Experimental results were obtained on both the Omega laser facility and the National Ignition Facility. To enable direct shock measurements, a refined analysis of Thomson scattering data was carried out using a new ray tracing algorithm. In our experimental configuration, an expanding plasma from a foil target interacts with several crossed laser beams, which exert a strong ponderomotive force on the flow. This ponderomotive coupling was enhanced by thermal effects from electron and ion heating, as well as electron heat conduction.

Large-scale simulations using the particle-in-cell (PIC) code VPIC provided valuable insight into the physics of shock generation and the response of flowing plasmas to crossing RPP laser beams. Simulations revealed freely propagating shocks with characteristics consistent with Thomson scattering measurements. The kinetic effects observed in the PIC simulations improved upon hydrodynamic modeling results from Ref. [2]. Specifically, the simulations highlighted strong ion heating caused by both the shock and the laser speckles, which was confirmed by Thomson scattering measurements in the downstream region of the laser spot. This ion heating resulted from interactions between cold flowing ions and electrostatic fields produced by the ponderomotive force of the laser speckles and associated electron pressure variations.

The results of this study highlight the importance of bow shock effects in underdense plasmas as a significant component of laser-plasma coupling scenarios.

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pF3D simulations of filamentation in Au foil reflection experiments at the NIF

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Recent experiments at the NIF were aimed at designing a transmitted beam diagnostic for measuring the spectrum and f# of a beam passing through a plasma under ICF conditions. These experiments generated varying levels of beam spray upon reflection from a plasma created by ablating an Au foil. For a 26^{o} incidence angle relative to the plane of the foil, the reflected beam sprays at relatively low intensities ($I \gtrsim 10^{13}$ W/cm^{2}), which are below the threshold for ponderomotive filamentation. The level of beam spray at a given intensity, as measured by the f# of the reflected beam, is reduced by going to a lower incidence angle of 8^{o} in the experiments.

A linear stability analysis shows that for plasma conditions relevant to the experiments, thermal filamentation occurs at a threshold that is significantly lower than the threshold for ponderomotive filamentation. We use the Python version of the code pF3D to simulate beam spray and filamentation in the experiments. For our initial conditions, we use one-dimensional plasma profiles extracted from radiation hydrodynamic simulations.

Our pF3D simulations confirm the existence of an intensity regime for which the beam is stable to ponderomotive filamentation but unstable to thermal filamentation. The simulated spread in f# at a given intensity is in good agreement with experimentally measured values. The simulations also recover the trend of decreasing beam spray toward lower incidence angles at a given intensity.

Finally, we note that although nonlocal heat transport enhances the level of beam spray, thermal filamentation, under the experimental plasma conditions, occurs even with classical Spitzer-Härm heat transport. This is consistent with theoretical expectations.

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Development of a transmitted beam diagnostic at the National Ignition Facility (NIF)*

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A transmitted beam diagnostic is a critical tool for diagnosing laser-plasma interactions (LPI) at the National Ignition Facility (NIF) and addressing the persistent drive deficit in inertial confinement fusion (ICF) experiments. Currently, simulations do not fully account for this drive deficit, and this new diagnostic aims to identify the missing key physics, such as forward stimulated Brillouin scattering (FSBS), absorption, filamentation, beam spraying, and beam deflection. At NIF, it is not possible to directly collect beam information after it interacts with the target. To overcome this limitation, we propose an experimental concept that collects beam data by glinting the beam off a foil into a dedicated diagnostic. A simple proof-of-principle experiment has already been successfully conducted at NIF, demonstrating that a NIF beam can be glinted from a foil and characterized using the Full Aperture Backscatter Station (FABS) and the Scattered Light Time-History Diagnostics (SLTD). In this presentation we will share results of the data collected by these two diagnostics varying the angles of incidence and intensity into a gold foil.

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53rd Annual Anomalous Absorption Conference
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Multi-Species Hydrodynamics in Ignition-Scale Hohlraums on the National Ignition Facility*

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Interpenetration and multi-species (MS) ion physics have long been theorized to be important in gas-filled hohlraums on the National Ignition Facility (NIF) [1]. However, until recently, there has been limited ability to diagnose and quantify the dynamics of the hohlraum gas. Not only are MS physics of general scientific interest, understanding hohlraum dynamics is critical to the success of inertial confinement fusion (ICF). Ion behavior influences laser beam propagation, laser-plasma interactions, and capsule implosion symmetry. In this work, we will present results from a novel NIF platform where the hohlraum is filled with fusionable, DT gas[2]. As the hohlraum case, capsule and window ablate and expand, they compress and heat the DT gas within the hohlraum. This generates fusion conditions in the DT gas and produces neutrons. Given that the neutrons are kinematically mapped from the ion distribution, neutron diagnostics are used to infer the ion dynamics. The location of ion stagnation is measured with a novel wide-field-of-view neutron imager[3], the timing of the stagnation is determined through the burn duration, and ion energy/velocity/temperature distribution functions are inferred through neutron time-of-flight spectrometry. These data constrain our radiation-hydrodynamic hohlraum simulations, which now include a MS physics package, updated opacity models, and higher fidelity hohlraum engineering features. We will show synthetic data from the simulations that illustration how these more physically accurate models are a better representation of the hohlraum dynamics. The neutron observables act as constraints on the simulations and allow us to build confidence in our predictive capabilities.

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First Indirectly Driven Liquid-DT Filled Double Shell Implosions the National Ignition Facility*

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Double shell implosions aim to explore material mixing under fusion conditions in a volume burn geometry using high-Z metal pushers. High-Z pushers are more compressible than low-Z pushers enabling high stagnation pressure which reduces the required implosion speed while maintaining a low pusher adiabat despite strong shock heating. Additionally, the use of a small fuel mass reduces the fuel internal energy required for ignition, thus achieving stable platforms with reasonable fusion output to conduct controlled experiments. These factors make volume burn in a double shell implosion highly promising. Recently, a series of liquid-DT filled, indirectly driven, double shell implosions were conducted at the National Ignition Facility with laser drives reaching up to 1.5 MJ. These experiments achieved a maximum DT neutron yield of 1.67×10^{14} (yield - 479 J), DT ion temperature of 2.6 keV, fuel areal density (ρR) of 0.15 g/cm^2, and stagnation pressure of 79 Gbar. Further performance improvements are expected by enhancing outer-to-inner shell kinetic energy transfer and refined mitigation of degradations from engineering features such as the outer shell joint, fill tube, and surface roughness.

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Post-Shot Simulations of Liquid-DT Filled Double Shell Experiments

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Three liquid-DT filled double shell capsules were tested at the National Ignition Facility (NIF) within the past year, with a fourth one being fielded on March 30th, 2025. These shots are the first to feature a molybdenum inner shell within LANL's inertial confinement fusion (ICF) Double Shell campaign.

In this talk, we will review integrated hohlraum simulations of these first four shots using xRAGE[1,2], LANL’s Eulerian radiation hydrodynamic code. This discussion will cover the design reasons for a thicker aluminum outer shell, which saw an increase in radius from 128 um to 140 um, and the additional gold in the aluminum outer shell joint gap, which increased the gold liner from 140 nm to 300 nm. We will also examine the impact of a higher laser energy drive on the capsule's performance between the first two shots (1.25 MJ) and the last two shots (1.5 MJ). Additionally, we will explore how detailed metrology enables higher fidelity simulations, e.g. the latter two experiments had comprehensive measurements of the outer shell’s joint gap, which is a well-known degradation mechanism. A key goal of this campaign is to increase the neutron yield for better data acquisition. One of the ways to do so is by moving to a higher energy laser drive, with the next increase to1.8 MJ. By examining differences in nuclear performance and energetics between these four shots through simulation studies, we can refine our predictive modeling capabilities to better guide experimental design.

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3D simulations of density perturbations in plastic foil seeded by foam microstructure*

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In laser direct-drive inertial confinement fusion (ICF), foams can be used for laser imprint mitigation, and specific foam microstructures can be three-dimensional (3D) printed thanks to the recent progress of additive manufacturing capabilities. The numerical investigation of the effect of these microstructures on ICF implosions requires to perform 3D multiscale radiative-hydrodynamic simulations because of the 3D nature of the foam and the difference of sizescale between the microstructure and the foam layer. As a consequence, most of the ICF relevant simulations involving foams have so far been performed by assuming the foam as a homogeneous material with a density equal to the foam average density. However, the recent development of Excession, a 3D AMR-ALE radiative-hydrodynamic code [1,2], enables to consider the foam microstructure by meshing the struts and the pores accurately. We first validate our simulations by evaluating the ionization front speeds in foams for densities ranging from 30 mg.cm^{-3} to 250 mg.cm^{-3}. They are found to be in good agreement with previous theoretical and numerical results[3,4], and the comparison to simulations where the foam is considered as a homogeneous material show similar ionization front speeds for foam densities larger than ~100 mg.cm^{-3}. In this density range, the homogenization wave starts propagating earlier and the ionization wave propagates in a homogeneous material, where we find the struts pre-expansion to be negligible. We then investigate the evolution of the density perturbations in a plastic foil covered by a foam layer. It is observed that the foam microstructure can seed significant perturbations which wavelength corresponds to the size of the pores. This work opens the way to integrated simulations of the imprint smoothing capabilities of foams on target implosions, but also the effect of their own imprinting characteristics.

* This work is supported by the U.S. Department of Energy (DOE), Office of Science, Fusion Energy Sciences, under Award No. DE-SC0024863: IFE-STAR and AWD-00007026: INFUSE.

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Low-mode nonuniformity in direct-drive implosions due to laser-smoothing techniques employed on OMEGA*

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A systematic source of implosion nonuniformity inherent in OMGA implosions has been identified as the interaction of cross-beam energy-transfer (CBET) with OMEGA's polarization smoothing (PS) and smoothing by spectral distribution (SSD) systems.

For successful laser-direct-drive implosions, the target compression must be highly uniform over the target. On OMEGA, multiple lasers are used to quasi-uniformly illuminate a target. High-mode number nonuniformities due to laser speckle on each individual beam are reduced by PS using distributed polarization rotators (DPRs) and 2D-SSD. The DPRs split each beam into two orthogonal polarizations and result in nearly linearly polarized regions on the edges of each beam profile, while the 2D-SSD bandwidth varies the time-averaged beam wavelength across the beam profile. Since CBET coupling between beams crossing in the coronal plasma is strongly dependent on the relative polarizations of each beam and the wavelength difference between them, this creates intensity variations across each beam profile that are different and unique for each beam.

DPR PS and 2D-SSD have been incorporated into a CBET model by treating each OMEGA beam as several copropagating subbeams with different polarizations, wavelengths, and offset. Significantly nonuniform laser-energy absorption distributions are predicted over the target primarily in low spectral mode numbers.

The systematic $l = 1$ mode in the predicted absorption distribution is consistent with the direction of a systematic core flow that has been observed in OMEGA implosions. This suggests that CBET and PS/SSD interactions are likely the source of the systematic flow. When beam mis-pointing and power imbalance measurements are also included, the CBET model predicts $l = 1$ modes that are consistent with the specific core-flow directions measured for two shots sets—one with PS and the other without.

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Precision single-shot measurements of plasma conditions using a broadband probe*

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Precise knowledge of plasma conditions is critical for accurately modeling laser-plasma interactions relevant to inertial confinement fusion. Traditionally, optical Thomson scattering (OTS) has been employed to diagnose these plasmas. However, since the scattered light is seeded by random plasma fluctuations, the measured signals are typically extremely low; signal to noise can therefore be a challenge or require working with high OTS probe intensities which can in turn affect local plasma conditions.

It was recently proposed that a low energy broadband probe laser could be used to measure the properties of plasmas irradiated by a high-power laser, by having the probe couple to the high-power "pump" via plasma waves [1]. The ion-acoustic resonances can be "imprinted" onto the probe spectrum, producing the same spectra as those obtained with OTS off ion waves and revealing the same information (plasma temperature and flow)—but with signal levels that are many orders of magnitude higher.

This concept was demonstrated at the Jupiter Laser Facility, by leveraging the recent upgrade of the Janus laser with the STILETTO system [2], a high-bandwidth time and frequency pulse-shaping device. The experimental campaign used CH4 and CO2 plasmas across more than 50 shots, spanning a range of pump intensities, background densities, and timing offsets between the pump and probe. Using nonlinear regression models, we extracted various plasma properties with high precision and compared them to independent measurements from the same experimental campaign. Besides its application as a plasma probe, this technique can also generate the gain curve of crossed-beam energy transfer (CBET) in a single shot (instead of multiple shots scanning the pump-probe wavelength separation [3]), and paves the way for new experimental investigations of CBET and other laser-plasma instabilities [2].

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Modeling the Impact of THOR Windows on Capsule Implosion Symmetry

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The achievement of ignition and gain on the National Ignition Facility (NIF)[1] provides the opportunity to develop novel experiments that leverage the energy produced by the capsule implosion. High yield capsule implosions on the NIF are fielded inside of a cylindrical hohlraum, which is used to convert laser energy to X-rays that drive the implosion. In high yield implosions, X-ray fluxes from hohlraum re-heating have been observed to exceed the fluxes generated from the initial laser drive[2]. This opens the possibility of utilizing this X-ray output to drive radiation flow experiments and opacity measurements relevant to astrophysical conditions that are otherwise unattainable in the laboratory. The THOR campaign on NIF seeks to develop this capability.

A central challenge in this effort is designing windows that are thin enough to allow radiation to burn through and escape the hohlraum, yet sufficiently robust to prevent a long-wavelength drive asymmetry that could inhibit ignition. To address these sensitivities, systematic studies using xRAGE have been conducted to quantify the shape distortions imposed on these implosions. Simulations predict that variations in window thickness, material density, and X-ray absorption properties induce measurable asymmetries that can be mitigated through optimized design.

A series of planned experiments will validate these models, systematically scanning window materials, thicknesses, and laser configurations to minimize perturbations while maximizing radiation throughput. The experimental data will refine our predictive models and inform the design of a high-yield layered implosion with THOR windows. This presentation will discuss the modeling strategy, expected asymmetry trends, and experimental validation efforts supporting the development of THOR as a platform for future high-energy-density science.

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A Machine Learning-Driven Solution for Denoising Inertial Confinement Fusion Images

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Neutron imaging is important in optimizing analysis of inertial confinement fusion (ICF) events such as those at the National Ignition Facility (NIF) and improving current and future ICF platforms[1]. However, images of neutron sources are often degraded by various types of noise[2]. Salt and pepper noise introduces black and white spots that impede the readability of the image. Gaussian and Poisson noise often coexist within one image, obscuring fine details and blurring edges. Uniform noise causes random shifts in energy, brightness, and intensity[3]. These noise types often overlap, making them difficult to distinguish and remove using conventional filtering and thresholding methods. As a result, noise removal techniques that preserve image fidelity are important for analyzing and interpreting images of a neutron source. Current solutions include a combination of filtering and thresholding methodologies[4]. In the past, machine learning approaches were rarely implemented due to a lack of ground truth neutron imaging data for ICF processes. However, recent advances in synthetic data production, particularly in the fusion imaging field, have opened opportunities to investigate new denoising procedures using both supervised and unsupervised machine learning methods[5]. In this study, we implement an unsupervised autoencoder with an Anscombe Transform in the latent space for mixed Gaussian-Poisson denoising. The network successfully denoises neutron imaging data and demonstrates lower reconstruction error when compared to regular autoencoders and non-ML-based filtering mechanisms. This approach presents a promising advancement in neutron image noise reduction and neutron data analysis for optimal ICF experiments.

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Updates on Nuclear Imaging Capabilities at the National Ignition Facility

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The Nuclear Imaging System (NIS), fielded at the National Ignition Facility (NIF), has been capturing neutron images of Inertial Confinement Fusion (ICF) driven implosions for over a decade. NIS has evolved from exploiting one Line of Sight (Los) to three nearly orthogonal LoS. This has made possible the regular visualization of the burning hotspot in 3D using limited view tomography algorithms. This imaging system has also allowed the reconstruction of the density distribution of the cold fuel surrounding the burning plasma. Furthermore, two of those lines of sight have been equipped to capture gamma-ray images, creating an opportunity to characterize the remaining ablator of the fuel capsule.

In addition to probing established capsule designs - that have led to the major achievement of ignition - the NIS diagnostic tool can also help survey new capsule designs, such as those used in Double Shell implosions. The imaging capabilities delivered by NIS continue to provide critical insight to assess fusion efficiency and to study ICF implosion performance.

LA-UR-25-22964

Particle-in-Cell Simulations of Burning Capsule Implosions*

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Anomalies observed in the neutron spectral shift of high-yield shots at the National Ignition Facility (NIF) suggest the presence of suprathermal ions[1], implying that kinetic effects play a significant role in burning Inertial Confinement Fusion (ICF) plasmas. Furthermore, recent measurements of reaction-in-flight (RIF) neutrons[2], and specifically alpha knock-on neutrons (AKN), can provide a direct probe of the stopping power in the burning fuel region of high-energy alpha and up-scattered D/T ions. We therefore aim to provide a tool capable of performing fully kinetic simulations of the complete capsule in burning implosions.

We have developed the radiation-particle-in-cell code PICNIC[3], an exactly energy-conserving, electromagnetic and fully relativistic particle-in-cell Monte-Carlo Collision (PIC-MCC) code capable of simulating the full burn stage in ICF. Collisions are handled with a moment-preserving binary-pair MCC algorithm for moderately coupled plasmas. The algorithm includes both cumulative small-angle Coulomb and single large-angle Rutherford scattering, as well as alpha-D/T nuclear elastic scattering to accurately model the alpha up-scattering of D/T fuel ions to multi-MeV energies in the burnwave. We present results of 1D spherical simulations of NIF shot N210808-001, with initial conditions provided by HYDRA[4]. We find that the suprathermal ions generated by large-angle collisions with fusion alphas produce an AKN signal consistent with experiments. However, we also find that large-angle collisions do not explain the large measured spectral shift[1].

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Nonlinear Modeling of Photochemically-Induced Gaseous Optical elements

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A proof-of-principle experiment[1] recently demonstrated dielectric mirrors made out of neutral gas, operating at fluences above 1.5 kJ/cm2 at 10 Hz repetition rate with diffraction efficiencies above 95%. By increasing the damage threshold by two or three order of magnitude compared to solid elements, such gaseous optics have a transformative potential for high-power laser applications such as Inertial Fusion Energy (IFE). Their operation relies on the modulated energy deposition of a low-energy "imprint" beam (such as a pair of overlapping beams) via absorption by a dopant element in the gas (e.g., ozone, for UV imprint beams). The resulting gas heating can initiate an acoustic/entropy wave which modulates the gas density and hence its refractive index, turning the gas into a grating or other diffractive optics elements. Here, we present results from a comprehensive modeling suite that includes: i) the chemistry of UV absorption by ozone and gas heating from the subsequent chemical reactions; ii) the nonlinear hydrodynamic response of the gas from a 2D hydrodynamic code[2] resolving Euler equations; iii) a 3D Fresnel diffraction code to calculate the diffraction of an external, high-power laser off the resulting index modulation. For small perturbations, the simulations show an excellent agreement with linear theory[3]. For stronger perturbations, nonlinear effects arise due to the depletion of ozone and nonlinear wave excitation. We will present comparisons with recent experiments at Stanford University and discuss future directions and applications of such gas-optics.

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Characterization of photochemically-induced transient gas gratings as final optics for inertial fusion energy lasers

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Transient diffraction gratings can be created in an ozone-doped gas flow using interfering deep-ultraviolet (DUV) lasers [1,2]. These gas optics can tolerate laser fluences around $1\ \mathrm{kJ/cm^2}$, three orders of magnitude higher than the damage threshold of conventional solid optics. Additionally, they only exist for around 1 μs and can be regenerated from shot to shot, making them inherently debris-resistant. These unique advantages make gas optics an ideal choice for final optics in inertial confinement fusion (ICF) applications.

In this work, we demonstrate using gas gratings to manipulate lasers at various wavelengths with high diffraction efficiency. For example, we achieved an efficiency of above 95% for a $532\ \mathrm{nm}$ probe beam with high stability over hours, utilizing $266\ \mathrm{nm}$ imprint beams with less than $10\ \mathrm{mJ}$ of energy. Furthermore, we systematically characterize the performance of ozone gratings under various experimental parameters, including imprint fluence, gas composition, and grating geometries. The experimental results help us better understand the physical properties and dynamics of these transient gas optics, validating a previously developed theoretical model [2] and suggesting practical parameters for ICF applications.

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Understanding and managing optics damage from laser-plasma instabilities on the NIF*

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Stimulated Brillouin scattering (SBS) produced in inertial confinement fusion (ICF) experiments on the National Ignition Facility (NIF) can cause significant damage to the laser transport mirrors. SBS is sensitive to many parameters (laser and plasma, as well as the amount of crossed-beam energy transfer used in the experiments), and the damage it can inflict to optical elements is also dependent on many factors (SBS fluence, but also its polarization, spatial profile, its intensity modulations due to diffraction off the NIF's continuous phase plates, as well as the random variations in damage threshold between NIF transport mirrors).

In this presentation, we will review the recent efforts made at understanding and mitigating optics damage from SBS on the NIF. A map of optics damage threshold for each of the 192 NIF beams was generated based on a comprehensive characterization of the existing data on SBS and optics damage, and compared to NIF data collected over more than a decade. Strategies for future mitigation of optics damage will be presented.

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Laser-Plasma Instabilities Driven by 1ω Pulses at Shock Ignition Conditions

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Laser-plasma interaction (LPI) at the intensities often observed in shock ignition schemes are dominated by parametric instabilities, which can be detrimental to Inertial confinement fusion (ICF) implosion experiments. Recent experiments led by G. Cristoforetti[1] at the PALS laser facility using 1ω (λ=1.314 µm) laser pulses at the PALS facility were found to excite various parametric instabilities such as Stimulated Raman scattering (SRS) and Two Plasmon decay (TPD. At the peak intensity ($I \sim 10^{16}$ W/cm^2), the high irradiance ($I\lambda^2$) and multi-keV electron temperature lead to conditions of interest to shock ignition.

We present 2D particle-in-cell (PIC) simulations of laser-plasma instabilities (LPI) at both the low ($\sim 10^{15}$ W/cm^2) and high intensity ($\sim 10^{16}$ W/cm^2) stages of the PALS experimental pulse for fully ionized plastic targets (CH). The PIC simulations are designed to match the corresponding density, temperature and bulk flow profiles predicted for these stages of the experimental pulses, using data from previously performed hydrodynamic simulations[2]. The simulations model the under-dense region of the plasma (0.03-1.05) to capture the growth of various LPI, with the effects of Coulomb collisions also included.

In both cases, Stimulated Brillouin scattering (SBS) is observed to be the dominant source of reflected electromagnetic (EM) radiation. TPD is observed to be the dominant source of electron-plasma waves (EPW) during the low-intensity phase, with SRS inefficient due to the small density scale length, restricting SRS convective gain. At higher intensities, the presence of TPD is observed to be impacted by the effects of beam filamentation, attributing to the dominance of SRS at this stage. The extracted 3/2 ω spectra from our simulations are shown to closely mimic the frequency spread behavior observed in the experiments, suggesting the PIC simulations have exhibited matching LPI behavior to that of the experiments. However, unlike the experimental results, an asymmetric signal between the red and blue-shifted peaks can be seen. Finally, using simple Markov Chain Monte Carlo (MCMC) techniques, we estimate the temperatures of hot electrons exiting near the quarter critical density and simulation boundary for both the TPD and SRS-dominated regimes.

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Xcimer's LPI risk assessment and mitigation program*

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An overview of recent progress on Laser-Plasma Instabilities (LPI) risk assessment and associated mitigation strategies at Xcimer is presented. We focus on evaluating the compatibility and integration of various LPI mitigation techniques within our unique laser architecture, and plans to test mitigation strategies on our Phoenix system upon completion. Detailed characterization of Xcimer's focal spot profiles is presented, emphasizing the distinctions in focal spot properties compared to established facilities such as LMJ, OMEGA, and NIF. Additionally, we explore the potential effectiveness of bandwidth enhancement strategies, particularly Smoothing by Spectral Dispersion (SSD), in suppressing filamentation, mitigating Stimulated Brillouin Scattering (SBS), and detuning plasma resonances. The implications of these findings for optimizing laser performance and reducing LPI is discussed.

Expanding Thomson scattering analysis to 2D electron velocity distributions*

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Understanding energy transport is plasmas is challenged by multi-dimensional nature of the physics. Temperature gradients and instabilities drive electrons in specified directions producing anisotropies in the electron velocity distribution function. Measuring the electron velocity distribution in two velocity dimensions opens a pathway to understanding anisotropic processes on a kinetic level. Here, angularly resolved Thomson scattering (ARTS) is shown to be sensitive to the 2D nature of the electron velocity distribution function (EDF) and a forward fitting algorithm is shown to allow 2D EDFs to be extracted from data. Paired ARTS spectra are measured with a 90-degree rotation of the plasma in order to reduce degeneracy in the extracted EDF. The extracted EDF can be further constrained by assuming a spherical harmonic decomposition for the distribution. Preliminary application of this technique to the problem of heat transport via electron conduction will be shown.

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Ray tracing model of Thomson scattering spectra including inhomogeneities and stimulated scatterings

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In Thomson Scattering (TS) diagnostics, a high probe beam intensity ($\sim 10^{14}$ W/cm^2) is often necessary due to the small scattering cross-section. At such intensities, the probe can enhance density fluctuations in the subthreshold regime of scattering instabilities[1] or induce nonzero convective gain for stimulated Raman (SRS) and Brillouin scattering (SBS) within the TS volume in inhomogeneous plasmas[2].

Motivated by results of interpenetrating plasma[3] and laser induced bow shock[4] experiments, a ray-based TS model has been developed to account for plasma inhomogeneity, convective SRS gain, and arbitrary scattering geometries. In this model, the Thomson scattered light is propagated through the plasma as family of rays. Each family represents a particular frequency that is chosen across the desired frequency range. This numerical model has been used to evaluate the flux of emitted radiation and has been compared with the Thomson scattered light spectra measured in the nonlinear stage of ion Weibel instability[3], and ponderomotively driven bow shock experiments[4].

Furthermore, the Fourth-Generation Laser for Ultra-Broadband Experiments (FLUX) at the Laboratory for Laser Energetics (LLE) enables a variety of broadband experiments. Interpreting the experimental results requires new simulation tools for broadband laser-plasma interactions. Our simulation tool will be used to interpret broadband experimental results, such as those planned for pump-probe experiments on FLUX at the LLE.

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Investigation of Raman Sidescattering in Indirect Drive Experiments on the OMEGA Facility

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Indirect drive inertial confinement fusion (ICF) experiments performed on the OMEGA laser facility using rugby-shaped hohlraums have shown significant Raman losses measured in the Full-Aperture Backscatter Stations (FABS) and in the Near-Backscatter Imager (NBI). The NBI data showed that the Raman light was collected mostly in the azimuthal plane formed by two crossing 21° and 42° incident beams, indicating that the Raman light may have been strongly refracted in the hohlarum and/or emitted in non-backward directions. The FABS at 42° showed Raman signals that could not be reproduced in simulations considering only backscattered emission[1].

Using experimental data from our OMEGA experiments, ray-tracing calculations and 2D radiative hydrodynamic simulation data from the TROLL code, we will show that the intricate plasma density profiles resulting from the ablator expansion give rise to significant Raman sidescattering, the orientation of these profiles thus becoming an important parameter in the growth of SRS in indirect drive experiments. The dominant contribution corresponds to sidescattered light emitted at 20°-40° off-backscattering which is then partly refracted outside the hohlraum, in the azimuthal plane formed by two crossing 21° and 42° beams, where it is collected by our diagnostics. We will also show that this result may be extended to larger scale experiments, at the megajoule energy level, on the National Ignition Facility or the Laser Megajoule. Finally, while Raman sidescattering is a well-known issue in direct drive ICF[2,3], our results represent the first evidence of this mechanism in indirect drive ICF.

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Impact of the near-forward stimulated Brillouin scattering in ICF experiments

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We first briefly outline a spatial gain model for the near-forward stimulated Brillouin scattering (FSBS) which tends to significantly increase the beam aperture. Our predictions evaluate the FSBS amplification gain depending on the plasma parameters and the laser optical smoothing techniques that are used, thus accounting for the impact of the phase plate, the temporal and polarization smoothing techniques often used in high-energy facilities[1,2]. The successful comparison with a well-diagnosed gas-jet experiment[3] and the associated paraxial simulations pinpoint the gain value above which the FSBS depletes the pump and increases the laser aperture[4]. Either in NIF or LMJ experiments, our predictions indicate a significant spray before the beam reaches the energy deposition region. The impact of this instability on the hohlraum physics and experimental outcome is then analyzed in light of an LMJ experiment by increasing, in the radiative hydrodynamic simulation, the beam aperture when the FSBS gain is important. We then discuss the impact of the FSBS on other wave-mixing processes that are sensitive to the beam spray angle such as the cross-beam energy transfer[5,6].

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Anomalously strong density fluctuations in plasmas subject to stimulated Raman scattering of nanosecond laser pulses

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Elucidating the kinetic processes that mediate laser-plasma interactions relevant to inertial confinement fusion has motivated extensive research over the past decades. Recent experimental investigations have greatly benefited from advances in Thomson scattering diagnostics, offering unprecedented insight into the spatiotemporal dynamics of these interactions.[1,2]

Kinetic effects typically cause distortions in the velocity distribution functions of the plasma species, which thus deviate from the Maxwellian shapes assumed in fluid models. Electron trapping in the nonlinear plasma waves driven by backward stimulated Raman scattering (B-SRS) is a well-known factor for such distortions, which can trigger secondary plasma instabilities. These phenomena have been observed, in particular, using short (~ 1 ps), single- or multi-speckled laser pulses.[3]

Here, we present experimental evidence for anomalously intense density fluctuations in plasmas experiencing B-SRS of nanosecond laser pulses. The experiments, performed at the LULI2000 facility, made use of multicolor Thomson probes in preformed He gas plasmas. The electron and ion density fluctuations were measured at different angles relative to the propagation direction of the laser drive (with ~ 0.5 ns pulse duration and $\sim 1.5\times10^{15}$ $\mathrm{Wcm^{-2}}$ mean intensity), and at wavenumbers distinct from those associated with B-SRS, backward stimulated Brillouin scattering or the Langmuir decay instability. In the presence of B-SRS, the Thomson scattering signals corresponding to the electron (ion) fluctuations were found to be amplified by a factor of more than 50 (resp. 1000).[4] In addition, and quite unexpectedly, strong electron density fluctuations at twice the electron plasma frequency $(2\omega_p)$ were consistently detected. Possible scenarios accounting for these results will be discussed.

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Center for Matter under Extreme Conditions: Energy Transport in HED Plasmas and Applications in Laser- and Pulsed-power-driven Experiments*

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In this talk I present selected highlights of the high energy density (HED) science research of the Center for Matter under Extreme Conditions (CMEC), the U.S. Department of Energy (DOE) National Nuclear Security Administration (NNSA) Center of Excellence. The Center's mission is to lead research and technological breakthroughs in HED Science, with an emphasis on the creation and diagnosis of extreme states of matter, both magnetized and un-magnetized. This is done by exploiting novel combinations of HED drivers and utilizing both modeling and experiments to develop a physics-based understanding of HED systems and train future scientists. To achieve this mission, CMEC integrates a multi-disciplinary team of leading HED scientists spanning key disciplinary areas, from planetary science to astrophysical and laboratory HED plasmas. The team's combination of expertise in experiments, modeling, theory, and diagnostics is critical to addressing the complex scientific challenges of understanding changes in materials' properties under extreme conditions and the strategic goals of the Stockpile Stewardship Program (SSP), in tight collaboration with the NNSA National Laboratories, and provide training and mentorship for students and young researchers. Here I focus on plasma instability and transport studies in laser-driven- and pulsed-power-driven experiments, designed and interpreted using an ecosystem of simulation tools spanning radiation magneto-hydrodynamics and kinetic regimes, with the FLASH And OSIRIS codes, respectively. I discuss magneto-Raleigh-Taylor unstable gas puff Z-pinches at UCSD's CESZAR and Cornell's COBRA, ion-Weibel and non-resonant instabilities in oblique collisionless shocks at the Omega Laser Facility of the Laboratory for Laser Energetics at the University of Rochester, and collisional self-magnetized shocks in the high-repetition-rate laser system of UCLA's Phoenix laboratory.

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Planar LPI experiments on the Laser Megajoule: first results*

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Data have very recently been obtained from directly-driven planar target experiments on the Laser Megajoule (LMJ). The experiments were designed to closely approximate the planar laser plasma interaction (LPI) series of experiments carried out over the past several years on the National Ignition Facility (NIF)[1]. By taking advantage of the time-resolved and wide angular coverage of the diagnostics available on the LMJ[2], it is possible to accurately quantify the total amount of stimulated Raman scattering (SRS) produced.

An additional aim of the experiments, again taking advantage of the available diagnostics, radiation hydrodynamic modeling, and symmetry of the illumination, is to further isolate and quantify the respective contributions from the various SRS mechanisms of: single quad backscatter, single quad tangential side scatter, and multi-beam (cooperative) scattering.

The results will be compared with the NIF data set. While reproducibility with NIF was one goal of the experiments, the LMJ interaction conditions are not identical. Specifically, the LMJ quads are linearly polarized (NIF is polarization smoothed) and have smaller focal spots. Additionally, the single quad intensities on the LMJ experiments were higher for the same overlapped intensities. The consequences of these differences will be discussed.

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Radiative Effects on Particle Direction in Counterpropagating Laser Pulses

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The radiation reaction force describes the recoil experienced by charged particles due to their own radiation[1]. Prior studies have found evidence of radiation reaction by examining energy loss in laser-electron beam collisions[2]. With the upcoming generation of intense laser facilities, the radiation-dominated regime is increasingly in reach. In this work, we identify a potential signature of radiation reaction for all-optical experiments.

Using 1D and 2D particle-in-cell simulations, we study the interaction between counter-propagating short laser pulses in an underdense plasma. We specifically consider the case where one pulse is both shorter wavelength and lower amplitude than the other. When radiation reaction is neglected, the longitudinal particle motion is typically biased in the direction of the shorter-wavelength pulse. However, a regime exists where the radiation reaction force causes a reversal in the dominant direction, such that the particles move with the higher-amplitude pulse. Through simple single-particle considerations, we estimate the range of wavelength and amplitude ratios for which the reversal occurs and show that the estimate broadly agrees with the simulated results. Finally, we suggest an experimental setup with which this effect could be investigated in high-power laser facilities.

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Impact of High-Z dopants in implosion core hydrodynamics*

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Inertial Confinement Fusion (ICF) experiments have consistently shown that the mixing of high-Z elements from the shell into the deuterium-tritium (DT) core significantly impacts fusion yield and overall performance. Considerable efforts have been made to model both the extent of material mixing and its influence on implosion hydrodynamics. However, it remains uncertain whether current physics models can accurately capture these effects. Nearly two decades ago, an experimental campaign at the Omega Laser Facility introduced pre-mixed high-Z dopants into the DT core at varying concentrations to assess their impact on implosion performance [1-3]. The study aimed to isolate the effect of the high-Z dopants in the implosion by introducing known amounts of different elements in the gas fill. They concluded that existing simulation codes failed to accurately replicate the experimental performance degradation. Building on this historical work, we revisit and expand upon the original study by comparing those experimental results to state-of-the-art radiation-hydrodynamic simulations using **xRAGE** [4]. Additionally, we conduct focused experiments designed to isolate and better understand the individual physical mechanisms by which high-Z dopants affect implosion dynamics. Our research seeks to address two critical questions: **Can our most advanced radiation-hydrodynamic codes (xRAGE) accurately model the effects of pre-mixed high-Z dopants in ICF implosions? If not, what key physics are missing from our current models?** By answering these questions, this study aims to improve the predictive capabilities of ICF hydrodynamic models and advance our understanding of high-Z impurity effects in fusion plasmas.

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Hydrodynamic modeling of shear-driven mixing layers*

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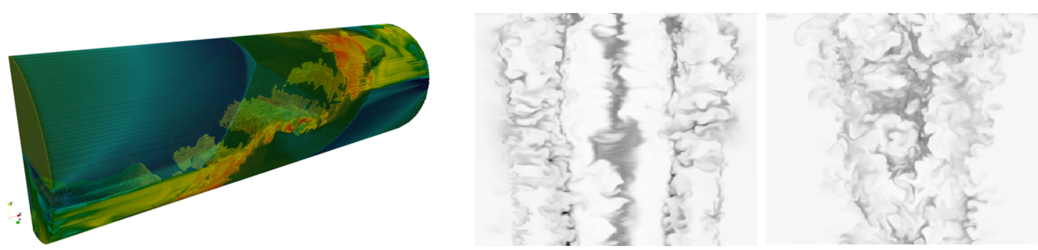
Inherently Three-Dimensional (3D) signatures have been observed experimentally in laser-driven shear experiments at the National Ignition Facility[1]. These signatures can be described as spanwise-aligned vortices or "rollers" at a mixing layer which eventually decay into statistically isotropic turbulence. Detail computational reproduction of these signatures require a 3D hydrodynamic model such as Implicit Large Eddy Simulation (ILES). In contrast, integral quantities like the thickness of the mixing layer can be estimated using a computationally cheaper 2D Reynolds-Averaged Navier-Stokes (RANS) model. Both models are implemented in LANL multi-physics code xRAGE[2].

We present detail ILES of a particular shear experiment where the temporal evolution of these rollers is compared for two different conditions: 1) smooth initial interface, and 2) rough initial interrace. These conditions are imposed using thin Copper foils with different surface roughness separating low-density plastic foams. Experimental radiographs showing the deformation of the foil inside the mixing layer are in excellent qualitative agreement with our simulations in Figure 1 at time 33 ns: Distinct rollers are still present with the smooth foil (middle) while they are absent with the rough foil (right).



Smooth Rough

Figure 1: 3D ILES: Transparent density colormap of the whole domain (left) and in-plane density at the shear layer in the center of the domain for the two different foils (right).

*This work was conducted under the auspices of the U.S. Department of Energy by Los Alamos National Laboratory under contract 89233218CNA000001.

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Simulations of electron and radiation preheat effects in laser-shocked 3D-printed plastic lattice media

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Los Alamos National Laboratory's Bosque campaign investigates how the mix[1] and thermalization of shell materials and fusion reactants affect fusion reactant rates. Here, mixing occurs via the shock-compression of a heterogeneous medium consisting of deuterated two-photon polymerization (2PP) 3D-printed lattices filled with tritium gas. Variations in lattice structure, such as unit cell geometry and lattice thickness, as well as in the gas fill composition enable a systematic approach in studying these mixing and thermalization effects. However, preheating from radiation and electron heat transport can alter upstream conditions ahead of the shock front, affecting the lattice conditions before shock compression.

In this study, we assess preheating effects on 2PP-3D lattice structures in shock-tube experiments conducted at the Omega laser facility[2]. In these experiments, OMEGA 60 beams irradiate a plastic ablator at one end of the shock tube at an intensity of 8×10^{14} W/cm^2, generating a shockwave into the lattice. Additionally, a solid plastic witness disk was printed in the center of the shock tube. Its expansion due to preheating effects was observed radiographically. This platform is subject to various preheating sources such as laser-generated hot electrons and hard X-rays, the radiative preheating from the shock, and non-classical electron heat flux due to steep temperature gradients.

Simulations are performed with the Eulerian radiation hydrodynamics code xRAGE. Radiative preheat effects are modeled with multigroup radiation transport, and electronic preheat effects are modeled with the reduced-order nonlocal electron transport model by Schurtz, Nicolaï, and Busquet (SNB). In particular, we extend the SNB framework to consider the effects of hot electrons on the experimental platform.

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

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[1] B. M. Haines, R.C. Shah, et al., "*Observation of persistent species temperature separation in inertial confinement fusion mixtures*," Nat. Commun. 11, 544 (2020)

[2] R.W. Vandervort, N. Christiansen, et al., "*Observation of laser-driven and shock-driven preheat effects on 3D-printed, two-photon polymerization plastic lattices*" High Energy Density Physics, *In Press*

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Resistive Magnetohydrodynamic FLAG Simulations of Instability Growth in the Double Cylinder Experiment*

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Predictive magnetohydrodynamic (MHD) simulations aid in the understanding of instability structures that lead to fusion yield loss in inertial confinement fusion (ICF) concepts; however, only recently have simulations of magnetized liner inertial fusion (MagLIF) been able to reproduce the more complex instability structures observed by experimental diagnostics.[1] To better understand these and other instabilities structures, the Double Cylinder experimental platform has been developed using the Z-machine at Sandia National Laboratories to generate various MHD instabilities, field diagnostics to observe them, and provide that data to codes for validation efforts. This high energy density (HED) platform drives a multi-megaampere current through a target consisting of two concentric beryllium liners and an on-axis rod separated by regions of deuterium fill. The drive pulse launches a shock from the outer liner onto the inner liner, which has a pre-imposed defect pattern that generates interacting Richtmyer-Meshkov instability (RMI) modes. The shock and the generated RMI modes then converge inward on an on-axis metal rod. Magnetic field (B-dot), VISAR, and PDV diagnostics characterize the load current, which can be used as a simulation input; X-ray radiography and X-ray diodes provide snapshots in time that can be used to validate simulation results.

This work uses the 2D resistive magnetohydrodynamics FLAG code to simulate experiments in the Double Cylinder campaign and shows that for an experiment where the inner liner is pre-imposed with axisymmetric grooves to generate RMI in the experiments, preliminary FLAG simulations are able to reproduces many of the features of the converging RMI structures.

*Work performed under the auspices of the U.S. DOE by Triad National Security, LLC and Los Alamos National Laboratory under contract number 89233218CNA000001. LA-UR-

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Controlling Brillouin Amplification with Flying Focus Pump Beams*

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Strongly-coupled Brillouin backscatter in plasmas offers a promising route towards the amplification of high-power laser pulses in compact systems. However, the success of this scheme requires control of several parasitic effects, such as premature scatter of the pump beam before it meets the seed. Advances in the production and modeling of laser pulses with controllable spatiotemporal structure offer new strategies to overcome these challenges.

Using fully kinetic, multidimensional particle-in-cell simulations, we show that pump beams with a flying focus that follows the propagation of the seed pulse can enable efficient Brillouin amplification over long interaction distances, while suppressing premature scattering instabilities of the pump. Restricting our study to over-quarter-critical plasma densities, where Raman scattering instabilities are suppressed, we use 2D simulations to obtain scaling relations for peak power and energy transfer efficiency of the amplified pulses as a function of the flying focus pump beam parameters and identify relativistic self-focusing of the seed as an important saturation mechanism. We then perform quasi-3D simulations in this regime to explore the impact of 3D diffraction on these scalings.

*This work conducted under the auspices of the DOE-NNSA under the award DE-NA0004131.

Laser Wavelength Dependence of Particle Acceleration Mechanisms in High Intensity Laser-Solid Density Plasma Interactions*

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The impact of laser wavelength on High Energy Density physics applications and diagnostics based on intense, short (sub-picosecond) laser-plasma of laser-solid interactions is considered. We investigate the generation of relativistic electrons and the subsequent ion acceleration due to target-normal sheath acceleration (TNSA) as laser wavelength is varied. It is found that for constant laser pulse energy the hot electron temperature, Te, scales with Iλ2 as expected. The dependence of ion acceleration on laser wavelength for high intensity, short (sub-picosecond) laser-solid plasma interactions is also investigated. Well-established scaling laws for both hot electron generation and target normal sheath acceleration are tested against detailed Particle-In-Cell computer simulations in a variety of geometries, including cases where realistic plasma density profiles as determined by a radiation hydrodynamics code are used.

* This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344, funded by the Office of Science Microelectronics Science Research Center under Grant SCW1907, and was supported by the Livermore Computing (LC) Grand Challenge Program.

Transmission Plasma Holograms for Generation of High-Intensity Pulses Carrying Orbital Angular Momentum

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Transmission plasma holograms are expected to be capable of diffracting and focusing high-intensity femtosecond pulses using optics of much smaller size than solid-state components[1-2]. Reflective plasma holograms imprinted on the flat surface of solid targets were shown to be able to convert Gaussian beams to Laguerre-Gaussian modes[3]. However, the high-quality surfaces and high density required for reflective plasma holograms limit their applicability for high-repetition-rate systems.

In this work, we show that plasma transmission holograms created by the interference of a reference beam with a Laguerre-Gaussian beam can efficiently convert an intense femtosecond Gaussian beam to a Laguerre-Gaussian mode. Three-dimensional particle-in-cell simulations show that more than 40% of the incident energy can be converted to the Laguerre-Gaussian mode for a femtosecond pulse with an intensity around $10^{17}\ \mathrm{W/cm^2}$. This approach allows for compact high-repetition-rate production of high-intensity vortex beams and highlights the generalizability of transmission plasma holograms to optics beyond simple gratings and lenses.

This work was partially supported by NSF Grant PHY-2308641 and NNSA Grant DE-NA0004130.

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Simulations of coronal plasma hydrodynamics in the laser–plasma interaction experiments at the Laser Mégajoule*

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Laser–plasma instabilities can degrade the performance of direct-drive inertial confinement fusion implosions. Stimulated Raman scattering (SRS) is one of the primary concerns because it can generate hot electrons, which prematurely preheat the fuel, impeding the compression, and the laser can be scattered away, reducing the energy coupled to the target. We have developed and fielded planar laser–plasma interaction experiments at the Laser Mégajoule, which utilize unique time-resolved and wide angular coverage diagnostics[1] to study the SRS mechanisms. Simulations of the experiments using the radiation-hydrodynamic code DRACO[2] will be presented, which demonstrate that direct-drive ignition-relevant plasma conditions have been achieved. The simulations show importance of cross-beam energy transfer from the inner to outer beam quads, when the beams propagate into the plasma. This prompted SRS experiments using the outer and inner beam quads separated in time. The computed plasma profiles are being used for subsequent calculations of the SRS scattered light gain and the development of reduced SRS models. The planar expansion of the plasma, evidenced by time-resolved x-ray imaging of its self-emission, is being compared to the simulations. Time-dependent measurements of SRS over wide angles provided indirect measurements of the hydrodynamics, which are compared to the simulations.

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Modeling thermal radiation waves in the Mooncat NIF experiment*

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The Mooncat NIF experiment (formerly known as Xflows[1]) uses a laser-driven hohlraum to create a supersonic thermal radiation wave in a titanium doped silica plasma. The titanium dopant allows absorption spectroscopy measurements to determine the temperature of the wave as it propagates in the silica.[2] Same-shot radiography reveals information about the shock that forms at the wavefront as the heat wave cools and slows. This technique has been used on the Omega laser to study near-supersonic thermal radiation waves,[3] radiation transport in stochastic media,[4] and the interaction between heat waves and shocks.[5] The Mooncat experiment will adapt this diagnostic technique for use on the NIF, which can create higher temperatures that are more closely related to astrophysical phenomena and burning plasmas in Inertial Confinement Fusion experiments. We present radiation hydrodynamics simulations of the hohlraum temperature source and the resulting thermal radiation wave in the silica plasma. These models are compared to data from the first full-platform Mooncat shots that were executed in July 2024. These data and simulations can be used to answer physics questions about the supersonic-to-subsonic transition of a Marshak-like heat wave, which is an important subject in radiation hydrodynamics.

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Simulations of self-magnetization in expanding high-energy-density plasmas*

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Understanding plasma self-magnetization is one of the fundamental challenges in both laboratory and astrophysical plasmas. Self-magnetization can modify the plasma transport properties, altering the dynamical evolution of plasmas. Most high energy density (HED) laser experiments on magnetic reconnection and unmagnetized collisionless shocks rely on either Biermann or Weibel mechanisms to self-consistently generate the magnetic fields of interest. Multiple HED experiments have observed the formation of ion-scale magnetic filaments of megagauss strength, though their origin remains debated. Models based on Particle-in-Cell (PIC) simulations have been proposed to explain magnetization[1,2], including plasma interpenetration-driven Weibel, temperature gradient-driven Weibel, and adiabatic expansion-driven Weibel. Here, we conducted 2D collisional PIC simulations with a laser ray-tracing module[3] to simulate plasma ablation, expansion, and subsequent magnetization. The simulations use a planar geometry, effectively suppressing the Biermann magnetic fields, to focus on anisotropy-driven instabilities. The laser intensity is varied between 10^{13}–10^{14} W/cm^2, which is relevant to HED and ICF experiments where collisions must be considered. We find that the plasma rapidly self-magnetizes via an expansion-driven Weibel process, generating plasma beta of ~100 with the Hall parameter $\omega_{ce}\tau_e > 1$ within the first few hundreds of picoseconds. Implications of plasma magnetization for heat transport are also discussed[4].

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Novel high-power and high-efficiency OEC laser-based high-gain shock ignition

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Blue Laser Fusion (BLF) aims to realize a laser fusion power reactor in the 2030s. We are focusing on three areas of innovation: high-pulse energy laser systems capable of delivering up to 10 MJ at high repetition rates of 1-10 Hz, high energy gain target designs, and reactor system design and implementation. We are developing a modular pulsed laser system with energy storage in an optical enhancement cavity (OEC) injected with a coherent beam combining (CBC) fiber-amplified laser system. The OEC is a Fabry-Perot cavity designed to store a large amount of energy in a two-mirror cavity by carefully synchronizing the round-trip time of the intracavity laser pulse with the next injected laser, achieving phase matching and stacking of the laser pulses. In collaboration with the California Institute of Technology and Osaka University, we have successfully demonstrated a 1.5m operating OEC with an enhancement of 58,000 times, where an input power of 1W is stacked to 58kW within the OEC. A 15 m OEC is currently under construction. Pulsed operation and CBC-OEC integration are being implemented to further scale the pulse energy towards 10kJ, and plans are underway to build a 150 m cavity.

By combining multiple OECs and input lasers, this architecture can achieve effectively broader spectral width, engineered polarization, high spatial beam quality, and precise pulse timing optimized for direct-drive IFE target implosion and fusion ignition with the high-gain shock ignition (SI) scheme[1]. The spike pulse intensities larger than 10^{15} W/cm^2 exceed the threshold intensity of laser-plasma instabilities (LPIs), such as stimulated Raman scattering (SRS) and two-plasmon decay (TPD), generating many hot electrons. However, hot electrons below 100 keV strengthen the shock wave. Crossbeam energy transfer (CBET) driven by stimulated Brillouin Scattering (SBS) can also be minimized, improving laser absorption. In collaboration with UCSD, we are investigating how to control LPIs in terms of wavelength dependence, including effective bandwidth and polarization dependence.

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Experimental observations of the non-resonant streaming instability during the early stages of quasi-parallel collisionless-shock formation

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Collisionless shocks arise in many astrophysical systems and are the likely source of the highest energy cosmic rays found in the universe. In particular, when collisionless shocks form in the presence of a background magnetic field that is aligned with the plasma flow, the so-called quasi-parallel configuration, efficient particle acceleration has been measured in astronomical observations [Johlander ApJ 914 (2021)] and in numerical studies [Caprioli ApJ 783 (2014)]. Because of the collisionless behavior within these systems, shock mediation and subsequent particle acceleration must occur through the generation of, and interaction with, turbulent electromagnetic fields. Laser-based experiments provide a unique means to create relevant plasma conditions in the lab to study the microphysics associated with electromagnetic field generation relevant to quasi-parallel collisonless-shock formation. To this end, a new experimental platform has been developed and fielded at the Omega Laser Facility that utilizes asymmetric plasma flows, aligned with a background magnetic field. Ion streaming instabilities are allowed to grow and the resultant field structures are characterized with proton imaging. Analysis of this data has identified the non-resonant streaming instability as the dominant field-generation mechanism during the early stages of quasi-parallel-shock formation at high Alfvénic Mach numbers [Bolaños PRE 110 (2024)]. Experimental and computational results will be shown and discussed.

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Preliminary results of planar experiments to characterize shock properties of wetted foams*

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Polar direct drive (PDD) wetted foam (WF) implosions have recently been recognized as a promising opportunity in the pursuit of inertial fusion energy. These implosions involve large targets filled with cryogenic liquid DT which wicks into an additively manufactured foam layer. The liquid DT serves as both the ablator and the fuel. This setup is thought to offer improvements over indirect-drive layered DT implosions due to increased laser coupling as well as relaxed symmetry and convergence requirements for ignition.[1]

The experimental campaign that is the focus of this work seeks to use a planar geometry to investigate laser ablation and shock propagation through heterogeneous media, namely 3D-printed lattices wetted with D_2 and warm surrogate targets consisting of lattice material in aerogel. Planar experiments have been conducted at OMEGA with the objectives of measuring ablation/shock propagation speeds and observing shock front evolution in these heterogeneous targets, which are driven at ignition capsule intensities of ~2.5e14 W/cm^2. Target fabrication involving thin windows has proven to be a major challenge for this campaign, however, VISAR data have successfully been collected and analyzed for several target variations. This work will review challenges in target and experimental design as well as preliminary VISAR measurements and plans for an upcoming OMEGA shot day seeking to make VISAR and Thomson scattering measurements.

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Self-similar growth rate in Rayleigh–Taylor and Richtmyer–Meshkov instabilities *

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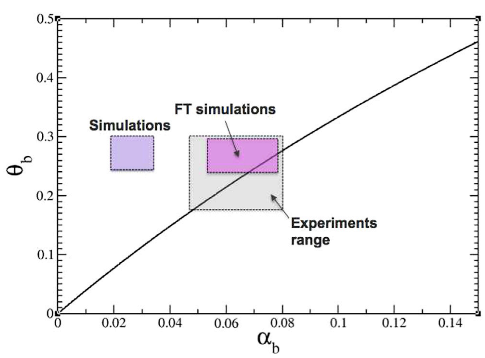
Interfacial instabilities play a crucial role in inertial confinement fusion (ICF) capsules, affecting both implosion symmetry and overall performance. The scaling parameters α in Rayleigh–Taylor (RT) and θ in Richtmyer–Meshkov (RM) instabilities are fundamental in describing the self-similar growth behavior of the mixing layer at the material interface. Extensive simulations and experiments have been conducted to determine these parameters, with results influenced by numerical algorithms, resolutions, and experimental measurement accuracy. In this work, we establish a unique relationship between α and θ using a simple buoyancy-drag mixing model. Our findings show that, for the same fluids, the self-similar growth rates of RT and RM instabilities are not independent. Instead, these scaling parameters are fundamentally linked by physical principles and depend on the fluids' drag coefficients. Consequently, α and θ are intrinsically coupled, each being a function of the other. The self-similar RT bubble growth rate (α_b) has been more extensively simulated and consistently measured in experiments than the RM parameter (θ_b). Therefore, we treat the RT bubble growth rate as a fundamental quantity and express RM growth scaling as a function of it. In our framework, the self-similar RT growth rate is governed by the bubble competition process—a merger model—at the mixing layer's edge. Our theoretical results are consistent with both hydrodynamic and laser-driven experiments. (LA-UR-25-22832)



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Quality-preserving laser-plasma ion beam booster via hollow-channel magnetic vortex acceleration*

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Laser-driven ion acceleration offers ultra-short (10s of fs for 10s of MeV), high-charge (100s of pC), and ultra-low slice emittance particle bunches. Mastering these sources can have a high impact on fundamental and applied research applications in physics, industry, and society, ranging from next-generation hadron colliders or neutrino factories, drivers for inertial fusion energy, radiotherapy, nuclear physics, warm-dense matter research, secondary radiation generation for material research and security applications, and possibly even radiation hardness of spacecraft. Despite clear progress in the last decades, particularly in the maximum ion energy using 1-10 Joule class laser systems, the desired energies for some applications still cannot be reached. Relieving the requirements imposed by a single laser-ion source, we present a staging concept that boosts a proton beam into the desired energy regime of 100s of MeV/u within a few compact, beam-quality-preserving plasma stages [1]. Our approach is based on magnetic vortex acceleration, using near-critical density targets with a pre-formed hollow channel to boost the energy of a temporally matched ultra-intense proton bunch. With fully self-consistent 3D particle-in-cell simulations using the exascale code WarpX, we demonstrate robustness in bunch acceptance (temporal and spatial), transport, energy boost, energy spread, and emittance preservation, using current and near-term available laser-system parameters.

*Simulations used the open-source particle-in-cell code WarpX in version 23.01. Primary WarpX contributors are with LBNL, LLNL, CEA-LIDYL, SLAC, DESY, CERN, and TAE Technologies. We acknowledge all WarpX contributors. This material is based upon work supported by the Defense Advanced Research Projects Agency (DARPA) via Northrop-Grumman Corporation. Partly supported by the U.S. DOE FES Postdoctoral Research Program via ORISE under Contract No. DE-SC0014664, the U.S. DOE Office of Science Offices of ASCR, HEP, and FES (including LaserNetUS) under Contract No. DE-AC02-05CH11231, and the Exascale Computing Project (17-SC-20-SC). This research used resources of the Oak Ridge Leadership Computing Facility at the Oak Ridge National Laboratory, which is supported by the Office of Science of the U.S. Department of Energy under Contract No. (DE-AC05-00OR22725, as part of an ASCR Leadership Computing Challenge (ALCC) award and the National Energy Research Scientific Computing Center (NERSC), a Department of Energy Office of Science User Facility using NERSC award FES-ERCAP0024250).

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A Path for Improving Laser Based Electron Radiography to Probe High-Z, HED Plasmas

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Laser-based relativistic electron radiography is an emerging technique for diagnosing HED plasmas[1,2,3]. There is growing interest in using laser generated electrons to compliment protons in measuring fields in high-Z plasmas, where the electrons prove to be a more penetrating probe. High-Z plasmas and the resulting fields generated are especially important for hohlraum dynamics[4], which in turn constrains the performance of ICF experiments. Thus better measurements of these conditions are paramount high-yield ICF designs. This work will outline the latest results on OMEGA EP based laser-electron radiography of high-Z plasmas as well discuss plans for improving the imaging diagnostics and future experiments on other lasers. Preliminary designs for magnetic optics to be used on laser facilities and synthetic radiographs using these optics will be shown, as well multi-probe radiographs using the betatron radiation generated by laser-plasma electron sources in conjunction with the electrons. The potential utility of this advanced laser-electron radiography will be discussed.

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Optically probing magnetic fields in near critical density laser-produced plasmas*

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Generation of magnetic fields in unmagnetized plasmas through both kinetic instabilities and hydrodynamic effects is critical to our understanding of both astrophysical and laboratory plasmas. Laser-produced near critical density and overdense plasmas in particular are of significant interest for laser-driven fusion schemes. Probing magnetic fields in this regime is a challenge due to high density (often solid) targets that are not transparent to optical probes. By taking advantage of the long wavelength, short pulse, relativistically intense CO_2 laser at Brookhaven National Laboratory's Accelerator Test Facility, we are able reach critical density using a gas jet target and probe both the plasma density and magnetic fields using a fs Ti:Sapphire probe beam. Magnetic fields are measured using Faraday rotation of the linearly polarized probe beam via an imaging polarimeter. By varying the delay between pump and probe beams we measure the temporal evolution of plasma density and magnetic fields simultaneously. With the aid of particle-in-cell simulations, we study distinct regions of the plasma where different magnetic field generation mechanisms dominate. In particular, for density and temperature gradients that are large relative to the local plasma skin depth c/ω_p both Biermann battery and Weibel instability generated magnetic fields can coexist within the underdense plasma on the front surface of the gas jet. Deeper into the plasma, where the laser cannot propagate, beam-plasma instabilities such as two-stream and current filamentation instability dominate the magnetic field structure. Both the shape of the neutral density profile and species of gas used affect the magnetic field structure significantly.

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Flow induced beam deflection measurements in ablation plasmas

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We measured flow-induced laser deflection in a well-characterized ablation plasma. Ion acoustic waves driven by the laser are enhanced when the transverse flow reaches the sound speed, driving density perturbations that cause beam deflection in the downstream direction[1,2].

By changing the timing of the deflection probe, different velocities are sampled in the ablating plasma. Ion acoustic damping is also adjusted by changing target material. The measured plasma conditions along the beam path are used to calculate expected deflection and refraction angles. Observed angles require ponderomotive beam deflection both for low and high ion acoustic damping plasmas and for subsonic and supersonic flows.

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