50TH ANOMALOUS ABSORPTION CONFERENCE 2022

Agenda

Sunday, June 5

5:00P	Registration		Registartion Starts
7:00P	Reception		Social Hour

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Monday, June 6

7:00P	Registration		Registartion Continues
Indirect-Drive Physics			
Chair: Albright	**Albright**	Speaker	Title
8:30A	Invited	Ross	Creating an igniting plasma on the National Ignition Facility
9:00A	Invited	Divol	Origins of variability in indirect drive inertial confinement fusion implosions with capsule gain >1
9:30A	Oral	Turnbull	Beam Spary Thresholds in ICF-Relevant Plasmas
9:50A	Oral	Farmer	Progress towards an inline beam deflection model for use in a radiation-hydrodynamic code
10:10A	Break		
Direct Drive Physics			
Chair: Montgomery			
10:30A	Invited	Colaitis	3D Simulations Capture the Persistent Low-Mode Asymmetries Evident in Laser-Direct-Drive Implosions on OMEGA
11:00A	Oral	Goncharov	Physics requirements for high-gain inertial fusion target designs
11:20A	Oral	Barlow	Optimization of Polar Direct Drive Illumination for Mega-Joule Laser Facilities
11:40A	Oral	Viala	Study of cross-beam energy transfer in spherical strong shock polar direct-drive experiments at the NIF
12:00P	Oral	Liotard	Influence of the solid-to-plasma transition on the laser energy deposition in targets and subsequent hydrodynamics for direct drive inertial confinement fusion
12:30P	Lunch		

Chair: Froula		Speaker	Title
7:00P	Plenary	Kruer	Fifty Years of Anomalous Absorption Conferences: the meetings that grew up with the quest for fusion and new frontiers in high-energy density physics
8:30P	Poster		
	P1	Schmitt	Anomalous ablative energetics of direct drive implosions at the National Ignition Facility
	P2	Belyaev	Mitigating LPI and gold bubble expansion using foams
	P3	Lester	Developing an Infrastructure for Automated Tuning of Hohlraum Simulations
	P4	Larroche	Some paths to model plasma collisions in inertial confinement fusion experiments
	P5	Kuczek	The Impact of Fill Tube Geometry on Recent High Yield Implosions at the National Ignition Facility
	P6	Olsen	Design of a direct-drive experimental platform for exploring the effects of heterogeneous mix on fusion burn
	P7	Milovich	Using Aerogel Foams to Improve Performance in Low-Density Gas-Filled Hohlraum Designs
	P8	Maximov	Nonlinear laser-plasma coupling caused by two-plasmon decay and crossed-beam energy transfer
	P9	Haberberger	X-ray schlieren refraction imaging
	P10	Tsung	Higher Dimensional Effects in Laser Plasma Interactions Relevant to Inertial Fusion Energy

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Tuesday, June 7

Alternate Indirect Drive Physics Platforms			
Chair: Moody		Speaker	Title
8:30A	Invited	Higginson	Understanding and controlling capsule symmetry in near vacuum hohlraums at the National Ignition Facility
9:00A	Oral	Lemos	Specular Reflections ("glint") of the inner beams in a gas-filled cylindrical hohlraum
9:20A	Oral	Ho	High rR Mo-dopped Be heavy ablator high yield: Experimental design and implosion physics
9:40A	Oral	Luedtke	Developing Predictive Modeling of Laser-Plasma Interactions for X-ray Radiographic Imaging
10:00A	Break		
Source Development			
Chair: Weichman			
10:30A	Invited	Palaniyappan	Vacuum laser acceleration of electrons using relativistic transparency injection
11:00A	Oral	Rinderknecht	Relativistically transparent magnetic filaments: A path to mega tesla fields and efficient gamma radiation
11:20A	Oral	Ramsey	Exact analytic solutions yielding flying-focus pulses
11:40A	Oral	Palastro	Nonlinear Thomson scattering with ponderomotive control
12:00P	Oral	Pierce	Arbitrarily structured laser pulses
12:30P	Lunch		

Chair: Turnbull		Speaker	Title
7:00P	Plenary	Edwards	Diffractive Plasma Optics for High-Power Lasers
8:30P	Poster		
	P1	Griff-McMahon	Magnetic Field Amplification in Underdense Plasma By Linearly Polarized Intense Laser Pulses
	P2	Brutus	Efficient Volumetric Diffractive Plasma Optics for Controlling High-Intensity Light
	P3	Fasano	Harmonic Generation in Reflection from Plasma Mirrors
	P4	Djordjevic	Transfer learning and multi-fidelity modeling of laser-driven particle acceleration
	P5	Qu	Creating observable QED collective plasma effects
	P6	Montgomery	X-ray Phase Contrast Imaging of Void Collapse in ICF Ablator Materials
	P7	Lezhnin	Focusability in the multi-pump Raman amplification of short laser pulses
	P8	Huang	High-yield and high-angular-fluence neutron generation from deuterons accelerated by laser-driven collisionless shock
	P9	Griffith	Increased Collective QED Signatures Throguh Particle Reflection
	P10	Weichman	Relativistically thermal plasma generation by magnetically assisted direct laser acceleration

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Wednesday, June 8

Cross Beam Energy Transfer			
Chair: Palastro		Speaker	Title
8:30A	Invited	Nguyen	Cross-beam energy transfer saturation by ion-trapping-induced detuning
9:00A	Oral	Seaton	Theory and simulation of cross-beam energy transfer mitigation through increased laser bandwidth
9:20A	Oral	Yin	Nonlinear cross-beam energy transfer model for ICF/HED design codes
9:40A	Oral	Edgell	Polarization-smoothing-induced nonuniformity in direct-drive implosions on OMEGA
10:00A	Break		
Instabilities			
Chair: Colaitis			
10:30A	Invited	Milder	Direct measurement of the return current instability
11:00A	Oral	Rousseaux	Experimental evidence of enhanced density fluctuations in plasmas experiencing stimulated Raman scattering of picosecond and nanosecond laser pulses
11:20A	Oral	Myatt	Stimulated Raman side scattering--important at last!
11:40A	Oral	Rovere	Scaling of hot electron generation from two-plasmon decay instability
12:00P	Oral	Solodov	Hot-electron preheat and mitigation in polar-direct-drive experiments at the National Ignition Facility
12:20P			Business Meeting
12:30P	Lunch		
2:00P	Archery Tag (Group Game)		Please let Raka know if you want to join this group activity at registration.
6:00P			Group Photo
6:30P			BBQ Dinner

Agenda

Thursday, June 9

Magnetized plasmas			
Chair: Strozzi		Speaker	Title
8:30A	Invited	Vogman	A two-species quasilinear model for current-carrying magnetized plasmas and its validation using continuum kinetic simulations
9:00A	Oral	Winjum	Parameter scan of stimulated Raman scattering in magnetic fields
9:20A	Oral	Lee	Effect of small normalized magnetic fields on rescatter of stimulated Raman scattering in the kinetic regime
9:40A	Oral	Reichelt	Influence of Self-Generated Fields on Hot Electron Transport in NIF Hohlraums
10:00A	Break		
Alternative implosion platforms			
Chair: Olson			
10:30A	Invited	Sio	Progress on magnetized indirect-drive implosions at the National Ignition Facility
11:00A	Oral	Strozzi	Modeling the first Magetized NIF Hohlraum Implosions
11:20A	Oral	Moody	The magnetized indirect drive implosion project on NIF
11:40A	Oral	Pearcy	ARES Simulations of Inverted Corona Experiments at the OMEGA Laser Facility
12:00P	Oral	Sauppe	Uncovering 3D Features in Cylindrical Implosion Experiments using the FLASH Code
12:30P	Lunch		

Chair: P. Michel		Speaker	Title
7:00P	Plenary	Bates	Suppressing parametric instabilities in direct-drive inertial-confinement fusion plasmas using broadband laser light
8:30P	Poster		
	P1	Wen	Mitigation of inflationary stimulated Raman scattering with laser bandwidth
	P2	Chase	Stimulated Raman backscatter in the kinetic regime of lasers with orbital angular momentum
	P3	Lee	Porting the particle-in-cell code OSIRIS to GPU-accelerated architectures
	P4	Rozmus	Bow shock formation in a plasma flowing across randomized laser beams
	P5	Joglekar	Unsupervised Discovery of Non-Linear Plasma Physics using Differentiable Kinetic Simulations
	P6		
	P7	Barfield	Measurements of anisotropic electron temperatures in magnetized gas-jet plasmas
	P8	Johnson	Experimental observation of the transition from electrostatic toward electromagnetic collisionless shocks in laser-driven plasmas
	P9	Leal	Modeling laser-driven ablative magnetothermal instability
	P10	Shaffer	An extended Vlasov-Fokker-Planck approach to laser absorption and ponderomotive transport effects

Agenda

Friday, June 10

Experimental platforms			
Chair: Bates		Speaker	Title
8:30A	Invited	Di Stefano	Modeling of a hybrid direct/indirect-drive scheme for producing complex hydrodynamic profiles involving co-propagating shocks
9:00A	Oral	Albright	Effects of mass ablation on fusion ignition and burn propagation in layered fusion capsules
9:20A	Oral	Epstein	Quantification and assessment of radiation-trapping efficiency in inertial confinement fusion implosion experiments based on characteristic quantities of simple models
9:40A	Oral	LeFevre	Experiments to study strongly coupled radiative shocks on the OMEGA laser
10:00A	Break		
Laser-plasma instabilities			
Chair: Milder			
10:30A	Oral	Simpson	High-energy two-color terahertz generation
10:50A	Oral	Weaver	Broad Bandwidth Laser Development for LPI mitigation at NRL
11:10A	Oral	Ludwig	Comparison of Optical Smoothing Techniques for Mitigation of Filamentation
11:30A	Oral	Cao	Predicting hot electron generation in inertial confinement fusion with particle-in-cell simulations
11:50P	Oral	Stark	Nonlinear Models for Coupling the Effects of Stimulated Raman Scattering to Inertial Confinement Fusion Design Codes
12:30P	Lunch		

Creating an igniting plasma on the National Ignition Facility

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Over the last half century, the pursuit of ignition and fusion gain has been the focus of research on numerous facilities around the world. Recently, using the laser indirect drive inertial confinement fusion (ICF) approach, experiments at the National Ignition Facility at Lawrence Livermore National Laboratory have entered the burning and igniting plasma regime producing a fusion yield in excess of 1.3 MJ on Aug. 8th 2021. These recent results were enabled by decades of sustained ICF research and demonstrate the importance of capsule material, scale and quality, cross beam energy transfer to control the drive symmetry, and improved low-fill hohlraums to increase radiation drive. In this new regime the rate of alpha particle heating from fusion exceeds heating loses from all other sources causing a feedback loop that rapidly increases the temperature and subsequently the fusion yield. This talk will present the experimental observables from the 1.3 MJ experiment and describe the key accomplishments that led up to this result.

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

Origins of variability in indirect drive inertial confinement fusion implosions with capsule gain >1*

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After a record yield of 1.35 MJ was achieved on the NIF layered implosion N210808, a series of near-repeats were fielded to assess the platform robustness, achieving fusion yields between 250 kJ and 700 kJ. This talk will describe these results and our current understanding of degradation mechanisms.

Two main sources of imperfection have been identified that can explain the observed performance variability. One is mode-1 asymmetry driven by target build and laser delivery, which can be estimated by detailed target metrology and NIF laser diagnostics respectively [1]. The mode-1 asymmetry can be diagnosed by measuring the bulk burning hotspot velocity with multiple time resolved neutron diagnostics [2]. This leads to a loss of coupling between the stagnating shell and the forming hotspot [3]. The other source of variability is localized ablator mix (jets, meteors) in the hotspot that somewhat correlates with capsule quality (voids and surface defects) and is quantified by combining multi-axis-frequency Xray imaging, neutron tomography and Xray spectroscopy [4]. Mix increases the hotspot radiative losses [5].

Both effects explain the observed variability and the impact on performance is in good agreement with simple HYDRA simulations.

[1] B. J. MacGowan et al., High Energy Density Physics **40**, 100944
[2] D. J. Schlossberg *et al.*, Phys. Rev. Lett. **127**, 125001(2021)
[3] O. Hurricane *et al.*, Phys. Plasmas 27, 062704 (2020)
[4] A. Pak *et al.*, Phys. Rev. Lett., **124**, 145001 (2020)
[5] C. R. Weber *et al.*, Phys. Plasmas **27**, 032703 (2020)

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

Beam Spray Thresholds in ICF-Relevant Plasmas*

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Beam-spray measurements suggest thresholds that are a factor of ≈2 to 15× are less than expected based on the filamentation figure of merit often quoted in literature. In this moderate-intensity regime, the relevant mechanism is forward stimulated Brillouin scattering (FSBS). Both weak ion-acoustic wave damping and thermal enhancement of ion-acoustic waves contribute to the low thresholds. FSBS imparts a red shift to the transmitted beam. Regarding the specific possibility of beam spray occurring outside the laser entrance holes of an indirectly driven hohlraum, this shift may be the most concerning feature owing to the high sensitivity of crossed beam energy transfer to the interacting beam wavelengths in the subsequent overlap region.[1]

*This material is based upon work supported by the DOE NNSA under Award Number DE-NA0003856, DOE/FES under Award Number DE-SC00221032, the University of Rochester, and the New York State Energy Research and Development Authority.

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[1] D. Turnbull *et al.*, “Beam-spray thresholds in ICF-relevant plasmas,” submitted to Physical Review Letters.

Progress towards an inline beam deflection model for use in a radiation-hydrodynamics code*

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A recent NIF experiment[1] has directly measured the power of specularly reflected (or glinted) light by the inner beams during the rise to peak power. Radiation-hydrodynamics simulations cannot reproduce the glinted light without an ad hoc decrease of the flux limiter. However, this decrease in the flux limiter cannot match the observed trends in time and gas fill. Directly driven beryllium[2] and gold[3] spheres also exhibit a discrepancy between simulated and measured laser coupling that cannot be explained by LPI processes. One hypothesis that could explain these results is that the incident laser is deflected by transverse flows[4,5] which moves the laser light to a shallower incident angle. This would decrease coupling by reducing the electron density at the laser turning point. Here, we outline the key physical effects that need to be included in an inline ray-tracing model of beam deflection. Further, we report on efforts to implement this reduced model into a radiation-hydrodynamics code and give a preliminary assessment of this process within the context of an ICF experiment.

* 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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[1] N. Lemos et al., “Measurements of specular reflections (‘glint’) of the inner beams in a hohlraum”, Bulletin of the American Physical Society 66 (2021).
[2] W. A. Farmer et al., Phys. Plasmas 27, 082701 (2020).
[3] W. A. Farmer et al., Phys. Plasmas 28, 032707 (2021).
[4] D. E. Hinkel et al, Phys. Plasmas 5, 1887 (1998).
[5] C. Ruyer et al., Phys. Plasmas 27, 102105 (2020).

3D Simulations Capture the Persistent Low-Mode Asymmetries Evident in Laser-Direct-Drive Implosions on OMEGA[*]

Presenter A. Colaıtis, D. Turnbull[†], I. Igumenschev[†], D. Edgell[†], R. C. Shah[†], O. M. Mannion[†], C. Stoeckl[†], D. Jacob-Perkins[†], A. Shvydky[†], R. Janezic[†], A. Kalb[†], D. Cao[†], J. Kwiatkowski[†], S. Regan[†], W. Theobald[†], V. Goncharov[†], and D. H. Froula[†]
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Laser-direct-drive implosion experiments conducted on the OMEGA laser system have been found to be prone to a systematic flow anomaly at stagnation. This anomaly persists across warm and cryogenic experiments and after elimination of other perturbation sources such as target offset, vibration, stalk and ice nonuniformity. Recently, a proposed explanation for this anomaly has been the polarized Cross Beam Energy Transfer (CBET) interaction in the particular OMEGA beam configuration of the Polarization Smoothing system, on the basis of post-processing with the BeamletCrosser tool developed at LLE.

Here, we present the first polarized CBET model fully coupled to radiative hydrodynamics. The polarized model is implemented in the IFRIIT 3D laser code, coupled to the ASTER 3D radiation hydrodynamics code. The coupled code is used to investigate 4 OMEGA shots considering various sources of low modes: pointing error, balance error, taregt offset, and polarized CBET.

The simulations reproduce bang times and neutron yields - when separately accounting for fuel age and high modes. The magnitude of the flow is well reproduced only when the low mode sources are large, whereas the modeling of stalk is thought to be required to match the flow magnitude in the remaining cases. For the cases explored in more details, polarized CBET - the only known systematic drive asymmetry, brought the results closest to the measured flow vectors, which may help explain the systematic flow orientation evident in the OMEGA implosion database. For typical current levels of beam mispointing, power imbalance, target offset, and asymmetry caused by polarized CBET, low modes degrade the yield by more than 40%. The current strategy of attempting to compensate the mode-1 asymmetry with a preimposed target offset recovers only about 1/3 of the losses caused by the low modes due to the dynamic nature of the multiple asymmetries and the presence of low modes other than l=1. Therefore, addressing the root causes of the drive asymmetries is apt to be more beneficial. To that end, one possible solution to the specific issue of polarized CBET (10 microns DPRs) is shown to work well.

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Physics requirements for high-gain inertial fusion target designs*

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Recent demonstration of 1.3 MJ of fusion yield with laser indirect drive at the National Ignition Facility and progress in target performance of laser-direct-drive inertial confinement fusion (ICF) implosions have sparked interest in using high-gain (*G* ~ 100) ICF target designs for various applications, including the Stockpile Stewardship Program and energy production. Although such progress is a critical step in providing basic ignition physic validation, a substantial amount of work remains to demonstrate not only that implosion physics can meet the high-gain requirements, but also that target and laser technology can be developed to efficiently drive these implosions. This talk will review the implosion physics that must be experimentally validated and discuss physics gaps that need to be addressed in the near future.

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

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Laser inertial confinement fusion (ICF) now enters the burning plasma regime, the next step is higher energy yield which requires coupling more energy to the target. Laser direct drive achieves improved coupling as there is no hohlraum acting as an intermediary. However, the Mega-joule laser facilities (National Ignition Facility and Laser Mégajoule) are configured with beams entering at the poles for indirect drive, and so require beam re-pointing to recover a direct-drive compatible illumination. A polar direct drive scheme has already been tested on the NIF,[1] however the irradiation configuration may not be optimal. The National Ignition Facility features: 8 cones of quads with independent wavelength tuning; 48 quads entering from different ports with independent pointing, power balance and defocusing; and the quads may be split to 192 beams with individual pointing offsets. There is a large parameter space which likely features different optimal setups for solid target illumination, conventional hotpot ignition, and shock ignition. Neural networks are a useful tool for the optimization of parameter space and have been used to more efficiently model ICF experiments.[2]

This talk presents an efficient search of the design space using a neural network[3] to optimize beam parameters reducing global RMS deviations from uniform illumination and to tune specific modes. The algorithm is trained using the 3D ray tracing package Ifriit.[4] The project will be extended to couple 3D hydrodynamics and off-line CBET analysis for a selection of ICF targets.

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[1] Hohenberger, M., et al. "Polar-direct-drive experiments on the National Ignition Facility." Physics of Plasmas **22**.5 (2015): 056308.

[2] Humbird, Kelli D., et al. "Transfer learning to model inertial confinement fusion experiments." IEEE Transactions on Plasma Science **48**.1 (2019): 61-70.

[3] Poëtte, G., Lugato, D. and Novello. "An analogy between solving Partial Differential Equations with MonteCarlo schemes and the Optimisation process in Machine Learning (and few illustrations of its benefits)", (2021).

[4] Colaïtis, A., et al. "Inverse ray tracing on icosahedral tetrahedron grids for non-linear laser plasma interaction coupled to 3D radiation hydrodynamics." Journal of Computational Physics **443** (2021): 110537.

Study of cross-beam energy transfer in spherical strong shock polar direct drive experiments at the NIF

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When the interaction parameter $I\lambda_L^2$ crosses the threshold of $\sim 10^{14}$ Wμm^2/cm^2, the laser plasma interaction becomes prone to numerous couplings between electromagnetic and plasma waves[1]. Most of these additional processes have non-linear behaviors and are in general harmful to the implosion in inertial confinement fusion. It is notably the case of the cross-beam energy transfer (CBET), a non-linear laser/plasma coupling effect that is paramount in ICF implosions. CBET can lead to a net transfer of energy between incoming and outgoing beams that affects both the symmetry of the implosion and the laser-target coupling[2].

In this talk, I will present 3D simulations of Polar Direct Drive (PDD) experiments[3] carried out on the NIF. These experiments aimed to study the efficiency of the laser energy coupling to a spherical target with beam intensities close to the SI regime. Two series of shots were simulated: N190204 (a 1100 µm CD+CH radius target with 3.0×10^{15} W/cm^2 peak intensity and 5 ns pulse) and N210519 (a 1050 µm radius CH target with 8.0×10^{14} W/cm^2 peak intensity and 7 ns pulse)[4]. These shots are simulated with and without CBET to investigate its influence on compression and coupling efficiency using the IFRIIT + ASTER[5] coupled codes.

We observe that with CBET, there is a large loss of total energy absorbed for both shots. The energy absorption decreases from 85% energy absorption without CBET to 40-60% absorption (and drops at 30% relative absorption during spike) with CBET. These energy losses occur mainly around the equatorial plane, where the overlap between the beams is much more extreme therefore inducing more CBET. This results in an inhomogeneous compression that is much stronger at the poles, leading to the creation of a pancake-shaped shock, and to several ns delays regarding the convergence time. We present comparisons of these results to angularly-resolved density profiles extracted from radiography data.

[1] K. Tanaka, L.M. Goldman, W. Seka D., and al., Physical Review Letters **48**, 17 (1982)
[2] I.V. Igumenshchev, D.H. Edgell, V.N. Goncharov, and al., Physics of Plasmas **17**, 12 (2010)
[3] M.Hohenberger, P.B. Radha, J.F. Myatt, and al., Physics of Plasmas **22**, 5 (2015)
[4] K. Anderson, and al., APS-DPP (2020) and W. Theobald, and al., APS-DPP (2021)
[5] A. Colaïtis, I.V. Igumenshchev and al., Journal of Compulational Physics 443, (2021)

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

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Inertial Confinement Fusion (ICF) is a method of achieving nuclear fusion reactions by bringing a small mass of combustible material at high densities with the desired thermodynamic properties. To achieve this goal, high power laser beams are used to implode a spherical shell constituted of gaseous DT fuel surrounded by solid DT and a plastic ablator. The laser ionizes the plastic which is ablated and the target implodes due to the rocket effect. In radiation hydrodynamics codes modeling this process, the plastic ablator is supposed opaque to the laser radiation, i.e. an initial plasma state is assumed. The mechanisms that lead to the transition from solid state to plasma state of the ablator are not modeled in the aforementioned codes, whereas they may have an important role in implosion symmetry, target compressibility, shock timing, and hydrodynamic instabilities.

This work focuses on the introduction of a solid-to-plasma transition model in a 3D radiation hydrodynamics code, in order to study such an influence on direct-drive implosions. It is based on a recent physical model developed in Ref. [1] [2] which describes the solid-to-plasma transition of polystyrene (most of ICF ablators are composed of polystyrene). The hydrodynamic code is a numerical tool coupling the 3D laser propagation code IFRIIT [3] with the 3D Eulerian hydrodynamic code ASTER [4]. Simulations with a single beam have confirmed the validity of the implementation, and have provided information about the dynamics of the transition: the ablator undergoes the solid-to-plasma transition, i.e. transforms from transparent to reflective optical state, on a timescale of 50 ps. Simulations are then applied to the 60 laser beams configuration of the OMEGA laser facility. Test simulations conducted on warm targets show a modification in the spherical harmonics mode distribution of the target areal density (ρR), where the volume heating during the solid to plasma transition is then to smooth the predominant OMEGA modes. They also show a slightly modification of shock velocity in the target, probably due to the preheating of the inner ablator. We will also present results for cryogenic cases at different adiabats and explain why this work is particularly relevant to new designs employing plastic ablators and/or foams, such as the Dynamic Shell concept.

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[1] G. Duchateau et al. , "*Modeling the solid-to-plasma transition for laser imprinting in direct-drive inertial confinement fusion*", PRE, **100**, 033201, (2019).

[2] A. Pineau et al, "*Modeling the electron collision frequency during solid-to-plasma transition of polystyrene ablator for direct-drive inertial confinement fusion applications*", Phys. Plasmas, **27**, 092703, (2020).

[3] A. Colaïtis et al, "*Inverse ray tracing on icosahedral tetrahedron grids for non-linear laser plasma interaction coupled to 3D radiation hydrodynamics*" JCP, **443**, 110537, (2021).

[4] I. V. Igumenshchev et al, "*Three-dimensional modeling of direct-drive cryogenic implosions on OMEGA*", Phys. Plasmas, **23**, 052702, (2016).

Chair: Froula		Speaker	Title
7:00P	Plenary	Kruer	Fifty Years of Anomalous Absorption Conferences: the meetings that grew up with the quest for fusion and new frontiers in high-energy density physics
8:30P	Poster		
	P1	Schmitt	Anomalous ablative energetics of direct drive implosions at the National Ignition Facility
	P2	Belyaev	Mitigating LPI and gold bubble expansion using foams
	P3	Lester	Developing an Infrastructure for Automated Tuning of Hohlraum Simulations
	P4	Larroche	Some paths to model plasma collisions in inertial confinement fusion experiments
	P5	Kuczek	The Impact of Fill Tube Geometry on Recent High Yield Implosions at the National Ignition Facility
	P6	Olsen	Design of a direct-drive experimental platform for exploring the effects of heterogeneous mix on fusion burn
	P7	Milovich	Using Aerogel Foams to Improve Performance in Low-Density Gas-Filled Hohlraum Designs
	P8	Maximov	Nonlinear laser-plasma coupling caused by two-plasmon decay and crossed-beam energy transfer
	P9	Haberberger	X-ray schlieren refraction imaging
	P10	Tsung	Higher Dimensional Effects in Laser Plasma Interactions Relevant to Inertial Fusion Energy

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50th Annual Anomalous Absorption Conference
Sky Top, PA
June 6-10, 2022

Fifty Years of Anomalous Absorption Conferences: the meetings that grew up with the quest for fusion and new frontiers in high energy density physics*

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The 50 Anomalous Absorption Conferences (AACs) represent a chronicle of a fascinating journey in science: the use of high power laser in the quest for laser fusion as well as for new spin-off applications. The first AAC was a 2 day meeting in 1971 at Princeton University to discuss laser plasma interactions. The meeting was adopted by the laser fusion program which began to rapidly grow in 1972 at LLNL and world-wide. AAC grew to become a 4.5 day with a much broader agenda to include many topics relevant to inertial fusion and high energy density science. This presentation will be a light-hearted, broad-stroke look back at the scientific journey witnessed in the 50 AACs. There were to be many learning curves along the way, but also many successes and scientific bonuses! What an adventure it has been.

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*This work was performed under the auspices of Lawrence Livermore National Security, LLC, (LLNS) under Contract DE-AC52-07NA27344. .

Anomalous ablative energetics of direct drive implosions at the National Ignition Facility*

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We present results from recent directly-driven double shell implosion experiments fielded at the National Ignition Facility (NIF) that indicate anomalous heating of the ablator shell resulting in decreased laser ablation pressure with respect to rad-hydro simulations for laser drive intensities at or below 250 TW/cm^2 at the capsule surface. Self-emission radiographs during the 6.5 ns laser drive pulse combined with backlit radiographs of the inner Cr shell between 15 and 17ns provided both the implosion trajectory of the CH ablator shell and the collision-driven implosion trajectory of the inner Cr shell. These data constrain the momentum of the residual ablator shell after the laser pulse as witnessed by the inner shell via its implosion trajectory during and after the inter-shell collision. Additional scattered light data indicates that 2% or less of the 1.1 MJ laser drive energy is scattered from the target. Simulations with the full laser drive over predict the implosion convergence speed of both outer and inner shells. Artificially reducing the laser drive power (by ~25%) to force a match to the experimental outer shell implosion trajectory results in an inner shell implosion trajectory that is too slow. Only by removing 16% of the laser drive energy and re-depositing this energy as thermal energy into the outer half of the ablator shell can one simultaneously match the trajectories of both shells. Results and implications of these comparisons will be given.

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

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Mitigating LPI and gold bubble expansion using foams

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We consider designs for indirect drive that partially fill the hohlraum with an ultra-low density foam (1.0 mg/cc SiO_2 aerogel). The specific design we consider is a scaled-down cylindrical NIF hohlraum (0.63x scale) intended to be shot on LMJ. We compare the foam-filled designs with standard C_5H_{12} gas-filled hohlraums, paying particular attention to the LPI and gold bubble expansion. The average hohlraum density in all of our designs is 0.55 mg/cc. Thus, the foam necessarily fills only a fraction of the hohlraum volume in the foam design.

We find that the best designs for mitigating *both* LPI and gold bubble expansion use a *combination* of high-Z foam and low-Z gas as the hohlraum fill material. In the foam design, SiO_2 aerogel is placed in a 0.8 mm thick cylindrical disk, overlapping the region where the outer beams strike the wall. Additionally, C_5H_{12} gas at 0.37 mg/cc fills the entirety of the hohlraum and penetrates the pores of the foam.

After the laser is turned on, the gas and foam plasmas interpenetrate and mix on micron scales. This generates a plasma with both high-Z (Si) and low-Z (H) constituents. Such a plasma is difficult to generate without use of a foam in cryogenic targets due to condensation of the fill gas. The placement of the foam over the site where the outer beams strike the wall tamps the expansion of the gold bubble into the hohlraum. This widens the channel between the capsule and the wall, allowing propagation of the inners to the hohlraum waist for more time.

The foam design has significantly lower inner beam SRS than the gas-only design. This is achieved via the presence of high-Z material in the foam, especially Si. The high-Z atoms lead to a greater inverse-brem absorption rate, increasing the electron temperature in the region of high SRS gain. This yields reduced SRS gains and reflectivities, as simulated using FLIP and pF3D.

SBS is kept in check via low-Z atoms in the foam, which facilitate efficient Landau damping of ion acoustic waves. Additionally, high ion temperatures generated in the foam plasma due to the foam microstructure further increase the Landau damping rate and aid in suppressing SBS[1].

Belyaev, M. A., et al. "Laser propagation in a subcritical foam: Subgrid model." *Physics of Plasmas* 27.11 (2020): 112710.

*Work performed under the auspices of the U.S. Department of Energy by LLNL under Contract DE-AC52-07NA27344 and supported by LDRD-21-ERD.041

Developing an Infrastructure for Automated Tuning of Hohlraum Simulations*

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Recent indirect-drive implosions at the National Ignition Facility (NIF) have demonstrated laboratory ignition[1]. In Inertial Confinement Fusion implosions on NIF, up to 1.9 megajoules of laser energy is delivered in pulses that are aimed at the inside of a Hohlraum used to generate X-rays that indirectly drive a capsule containing DT fuel, producing high yields from fusion reactions. Recent advances[2] in the Los Alamos radiation-hydrodyamics code xRAGE[3,4] have enabled it to model the integrated hohlraum and implosion dynamics.

xRAGE's Eulerian hydrodynamics and adaptive mesh refinement provide the unique ability to study the impacts of multiscale features in hohlraums, such as capsule support tents. Recent improvements to xRAGE's capability that enable the ability to model hohlraums include advancements to heat transfer, 3T equation of state and Non-Local Thermal Equilibrium (NLTE) physics.

The development of this new capability has created a need for an infrastructure to run these models. The complexities of the simulation setup present challenges for the user to ensure correctness prior to using large amounts of computational resources. We aim to understand the variations in different hohlraum setup models and account for changes the user needs to make in order to produce a valid model.

This study will aim to develop an automated methodology for hohlraum simulations within radiation-hydrodynamics code xRAGE. We will explore how various methodologies for simulating integrated capsule and hohlraum setups can enable the development tools in the pursuit of an automated tuning setup for future hohlraum models to match experimental data.

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

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[1] D. Callahan et al., “Achieving a Burning Plasma on the National Ignition Facility (NIF) Laser,” Bulletin of the American Physical Society AR01.00001 (2021).
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Some paths to model plasma collisions in inertial confinement fusion experiments

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In some inertial confinement fusion experiments[1,2,3], the hot plasma is not sufficiently collisional to be satisfactorily described by the Euler equations implemented in hydrodynamic simulation codes, particularly in converging regions of the expanding plasma flow. To better treat such situations, two mechanisms need to be accounted for, namely i) the collision and possibly interpenetration of different flows, and ii) the non-equilibrium features arising in the ion velocity distribution of each flow (or a single self-colliding flow). Accordingly, two kinds of physical and numerical tools are considered in this work.

To treat the non-equilibrium features in a single plasma, we develop an extended hydrodynamics model including higher moments of the ion velocity distribution function, together with physically justified closure assumptions and relaxation terms[4]. A preliminary one-dimensional numerical implementation of the model is shown to give satisfactory results in a test case involving a high-velocity collision of two plasma flows. Paths to extend that model to three dimensions as needed for an actual experimental geometry are briefly discussed.

To specifically treat the plasma collision/interpenetration problem, we develop a new multi-fluid, two-dimensional, Lagrange-projection, plasma hydrodynamics code[5]. First proof-of-principle runs are satisfactory.

For a routine modeling capability, both aspects must be implemented in a single two- or three-dimensional numerical tool. As a first step, we will shortly undertake the merging of the two "toy codes" described here, before going over to tentatively implementing the resulting model into a large radiative hydrodynamics code such as LASNEX[6] or TROLL[7].

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The Impact of Fill Tube Geometry on Recent High Yield Implosions at the National Ignition Facility*

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Implosions on the National Ignition Facility have recently achieved ignition[1]. Imploded capsules achieve high yields through the absorption of alpha particles produced by DT fusion reactions that heat the fuel, thus increasing reactivities further in a thermodynamic instability. Nevertheless, capsule implosions with significant alpha heating are particularly sensitive to asymmetries in fill tube and bore hole geometry.

Fill tubes have been shown to introduce jets of contaminant and high-density fuel into the hot spot and reduce fusion yield by introducing a low-density pathway into the central fuel region[2]. The addition of this complex nonlinear flow leads to a challenge of modeling the evolution of the fill tube jet in implosion experiments. The impact of fill tube geometry on fusion yield has been well documented from both experiments[3] and simulations[4]; although there have been seemingly counter-intuitive results, such as larger contaminant jets arising from nominally smaller fill tubes. A quantitative relationship between fill tube geometry and fusion yield has not yet been derived. We aim to understand how variations in the fill tube geometry and x-ray drive can impact capsule performance.

This study analyzes recent high yield shots at NIF through radiation-hydrodynamics code xRAGE. We intend to develop a more direct relationship between fusion yield and geometric details and pulse shape variations. We explore how the differences in bore hole and fill tube geometry influence capsule performance. The experimental results are given alongside simulated comparisons in: 1D, 2D with surface roughness, 2D with surface roughness and varying fill tube and bore hole geometries.

*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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[4] A. Pak et al., “Impact of localized radiative loss on inertial confinement fusion implosions,” Physical Review Letters **124**, 145001 (2020).

Design of a direct-drive experimental platform for exploring the effects of heterogeneous mix on fusion burn*

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Recent experiments to quantify the impact of heterogeneous mix on thermonuclear burn have demonstrated that assumptions of a single temperature in the mix region and a single scale length describing mix morphology may not be adequate for a heterogenous mix burn model [1,2]. The experiments were performed at the National Ignition Facility (NIF) and utilized *indirectly-driven* plastic capsules filled with a deuterated plastic foam of controlled coarseness, with tritium gas filling the voids in the foam [3]. A new approach utilizing larger (~2X diameter) *directly-driven* capsules with higher laser drive coupling will enable much higher (~100X to 1000X) thermonuclear yields in a much larger (~100X) burn volume. The higher yields will enable more constraining diagnostics including burn history measurements, neutron imaging, and spectroscopy (using dopants). The new, *direct-drive* capsules will be filled with a recently developed 3D printed lattice – opening a wide range of possible experiments, including specified location of deuterated lattice, controlled density and coarseness of the lattice, structures imprinted in the lattice, etc. The new experimental design is based upon the recent successful polar direct drive fusion neutron source platform at the NIF [4]. In this presentation, we will discuss design simulations (using HYDRA and xRAGE radiation-hydrodynamic codes) of the proposed *direct-drive* platform (the "Bosque campaign") and provide comparisons with simulations and experimental results of the previous *indirect-drive* platform (the "Marble campaign").

* This work was performed under the auspices of the U.S. Department of Energy by Triad National Security, LLC, operator of the Los Alamos National Laboratory under Contract 89233218CNA000001.

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Using Aerogel Foams to Improve Performance in Low Density Gas-Filled Hohlraum Designs*

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Reaching ignition in inertial confinement fusion (ICF) experiments requires that the central burning fuel be surrounded by a sufficiently symmetric shell of high areal mass density. In indirect drive, where a laser is used to illuminate the inside of a high-*Z* radiation cavity (hohlraum), symmetry can be accomplished by carefully aiming and tailoring the laser drive. This is particularly challenging if the hohlraum is filled with a low-density gas (to reduce Raman and Brillouin backscatter losses) due to the risk of incurring greater wall motion and loss of late-time symmetry control. To minimize this risk recent experiments have favored short pulses driving high-density-carbon (HDC) capsule ablators that require high initial pressures to melt the crystalline structure and avoid seeding of hydrodynamic instabilities. The National Ignition Facility (NIF) shot N210808[1] using an HDC ablator was able to achieve a record neutron yield on the threshold of ignition. This groundbreaking result was attained using the current maximum available energy of the NIF facility. Simulations indicate that additional gain may be realized by improvements in the HDC capsule and laser drive but exploring other options may significantly improve performance. To this end, we have revisited an earlier ignition design that employs a (non-crystalline) CH ablator[2] (allowing higher compression for a given laser energy at the cost of ~2x longer laser pulses) in a low-density gas-filled hohlraum to effect more benign plasma conditions. Simulations and recent experiments[3] suggest that impaired laser beam propagation by hohlraum wall expansion can be mitigated by using a ramp-down in laser power following the initial picket that sets the implosion adiabat. While this strategy is encouraging, additional improvements to late-time laser propagation are sought. We are investigating the possibility of adding a low-density (≥1 mg/cc, to minimize the onset of LPI instabilities) low-*Z* foam disc-like insert to act as a hohlraum wall tamper. In this work, we will present simulations of an upcoming experiment at the LMJ laser facility to test the viability of foam inserts in hohlraums.

*Work performed under the auspices of U.S. Department of Energy by LLNL under Contract DE-AC52-07NA27344 and supported by LDRD-21-ERD.041

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[3] N. Izumi et al. G04.00007 BAPS 66 (2021)

Nonlinear laser–plasma coupling caused by two-plasmon decay and crossed-beam energy transfer*

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In the plasmas of the direct-drive approach to inertial confinement fusion (ICF), there are two main laser–plasma instabilities that strongly affect the coupling of laser light power to the plasma corona: two-plasmon decay (TPD) that is localized in the plasma region near the quarter-critical density for the laser light, and crossed-beam energy transfer (CBET) that favors the plasma region where the plasma flow is close to Mach-1 magnitude.[1] In the ICF implosions on the OMEGA Laser System, both TPD and CBET are driven by a large number of overlapping laser beams, and the regions close to the quarter-critical density and close to Mach-1 flow can overlap.

We analyze the interplay between TPD and CBET in the plasma region near the quarter-critical density for conditions relevant to direct-drive implosions on OMEGA. Three-dimensional simulations of nonlinear laser–plasma interactions driven by the realistic intensity profiles of OMEGA laser beams have been performed using the laser-plasma simulation environment (*LPSE*).[2] The results of numerical simulations are compared with the theoretical analysis.

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

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[2] D. Turnbull, A. V. Maximov, D. H. Edgell, W. Seka, R. K. Follett, J. P. Palastro, D. Cao, V. N. Goncharov, C. Stoeckl, and D. H. Froula, Phys. Rev. Lett. **124**, 185001 (2020).

X-ray schlieren refraction imaging*

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In inertial confinement fusion implosions, the plasma density profile on the inner side of the driven shell is important to the performance of the design.[1] If the profile is of higher density or longer scale length than that predicted by hydrodynamic simulations, the mass increase in the hot spot can decrease its compressibility and reduce performance compared to what is expected from the simulations. Here we propose to measure the refraction of an x-ray probe using schlieren imaging, which can be more sensitive to the shape of the density profile inside the shell because of its dependence on the gradient of density as opposed to density itself. Deduction of the shape of the plasma density profile inside the driven shell using radiography is made difficult because of the following factors:

1. The x-ray energy required to produce a significant absorption in DT, which has a low opacity, is <1 keV where there are no strong line sources.
2. Even with a suitable x-ray energy of the backlighter, the large integrated absorption through the dense shell results in minimal sensitivity to the lower density release inside the shell.
3. Deduction of density from absorption relies on model-dependent opacity, whereas refraction relies on the real index of refraction, which depends primarily on the number density of electrons.

Ray-trace simulations indicate that schlieren refraction imaging has the potential to overcome the above-mentioned limitations to radiography.

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

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Higher Dimensional Effects in Laser Plasma Interactions Relevant to Inertial Fusion Energy*

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In inertial confinement fusion, laser plasma interactions, where the incident laser decays into a backward going light wave and a collective mode of the plasma can reduce laser coupling by reflecting the incident laser and also cause pre-heat which can degrade compression. In SRS and SBS, the instability itself is primarily one dimensional, meaning that the scattered light and the plasma waves both travel in the same direction as the laser. However, higher dimensional effects, which can be caused by laser speckles used by laser smoothing schemes, or higher dimensional effects in laser plasma interactions near the quarter critical surface such as side-scatter or the two plasmon decay, requires two- or even three-dimensional simulations. In this work, we will present two dimensional and three-dimensional multi-speckle simulations of laser plasma interactions relevant to current and future ICF experiments and demonstrate the kinetic nature of these instabilities.

*Work supported by DOE and NSF.

Agenda

Tuesday, June 7

Alternate Indirect Drive Physics Platforms			
Chair: Moody		Speaker	Title
8:30A	Invited	Higginson	Understanding and controlling capsule symmetry in near vacuum hohlraums at the National Ignition Facility
9:00A	Oral	Lemos	Specular Reflections ("glint") of the inner beams in a gas-filled cylindrical hohlraum
9:20A	Oral	Ho	High rR Mo-dopped Be heavy ablator high yield: Experimental design and implosion physics
9:40A	Oral	Luedtke	Developing Predictive Modeling of Laser-Plasma Interactions for X-ray Radiographic Imaging
10:00A	Break		
Source Development			
Chair: Weichman			
10:30A	Invited	Palaniyappan	Vacuum laser acceleration of electrons using relativistic transparency injection
11:00A	Oral	Rinderknecht	Relativistically transparent magnetic filaments: A path to mega tesla fields and efficient gamma radiation
11:20A	Oral	Ramsey	Exact analytic solutions yielding flying-focus pulses
11:40A	Oral	Palastro	Nonlinear Thomson scattering with ponderomotive control
12:00P	Oral	Pierce	Arbitrarily structured laser pulses
12:30P	Lunch		

Understanding and controlling capsule symmetry in near vacuum hohlraums at the National Ignition Facility

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The near vacuum hohlraum platform is an inertial confinement fusion design on the National Ignition Facility (NIF) that uses the lowest practical density of helium gas of 0.030 mg/cc to fill the hohlraum; 10 times lower than now used routinely. This has several advantages, such as high laser coupling; however, the inability to understand and simulate the symmetry of the imploded capsule has limited the use of this platform. This work presents the first simulations that are able to accurately capture the highly prolate implosion seen experimentally without unphysical, ad hoc model changes. While previous investigations attributed this asymmetry to multi-species interpenetration in the hohlraum, we find this alone has little effect on symmetry. Instead, it is the presence of crossed-beam energy transfer (CBET), occurring with no applied wavelength shift between the laser beams, that increases the laser power to the inner cones and causes a more prolate implosion. The effect of CBET is increased in the simulation model when the hohlraum laser entrance hole (LEH) hardware is included. Using this understanding, CBET is exploited by shifting the inner-beam wavelength by -0.75 angstrom (at 1 omega) with respect to the outer-beams. This transfers laser power to the outer-beams, in contrast to positive wavelength shifts, as done routinely on NIF, and produces a round capsule implosion in our simulations. This work shows the possibility of the near vacuum hohlraum as a viable experimental platform.

* Prepared by LLNL under Contract DE-AC52-07NA27344.

Specular reflections (“glint”) of the inner beams in a gas-filled cylindrical hohlraum *

N. Lemos, W. A. Farmer, N. Izumi, H. Chen, E. Kur, A. Pak, B. B. Pollock, J. D. Moody,
J. S. Ross, D. E. Hinkel, O. S. Jones, T. Chapman, N. B. Meezan, O. L. Landen, and
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At the National Ignition facility in inertial confinement fusion (ICF) experiments there are several processes that can absorb or re-direct the laser energy, reducing the x-ray drive and symmetry, reducing thermonuclear burn efficiency. In this work we quantify one of these processes – inner beam specular reflection (“glint”) off the hohlraum wall. The inner beams can glint and escape through the opposite laser entrance hole of the hohlraum [1,2] and this can be a potential coupling loss mechanism. We present experimental measurements that show that the total measured glint off the inner cone beams is less than 8 TW instantaneous, representing < 2% of the total laser power at peak power. Three different hohlraum gas fills densities were used: 1.2, 0.6 and 0.3 mg/cc, where the highest fill density showed no glint signal the two other fill densities showed similar glint signals. Comparing ray-tracing simulations with experimental results we were able to determine that inner beam glint is dominated by the lowest angle 21.5° beams within a 23.5° quad and it is at most 30% sensitive to different quad polarization arrangements.

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* 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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High ρR Mo-doped Be heavy ablator for high yield: Experimental design and implosion physics

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Beryllium ablators with inner layer doped with increasing Mo concentration towards the center can increase ρR and the burn fraction. The mass of this type of "heavy ablator" is $\geq$ 30% than conventional ablators with same radius. In the inner region of the ablator where Be is blended with Cr or Mo, the alloy has an amorphous glass-like quality. This can potentially reduce the mix caused by the structure non-uniformity in HDC ablators. Implosion simulations of heavy ablators with acceptable RTI and high yield were reported.[1] Based on this, implosion experiments with capsule radius of 1175 µm using 1.9 MJ of laser energy is designed. In capsule only simulations, this design gives higher 2D yield and YoC (ratio of the simulated high-mode 2D yield to 1D yield) than that of the HDC shot N210808, which gives record fusion yield using 1.93 MJ of laser energy. Integrated hohlraum simulations shows adequate radiation symmetry that gives yield, without surface roughness, close to 1D. Because of the radiation trapping nature, heavy-ablator implosions can tolerate large amount of Mo, potentially getting to the center from the fill-tube jet, in the hotspot. We also present high-yield robust designs that have YoC $\sim$ 1. With the same capsule radius and peak T_{r}, robust heavy-ablator implosions give higher yield and burn fractions than that using conventional ablators. Recent experiments using gas capsule with graded Mo in Be shell shows the effectiveness of this concept in preventing shell breakup.[2] Thus, heavy ablator provides a promising alternate path to ignition and high yield. An increased effort on this undertaking is therefore particularly timely.

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*Prepared by LLNL under contract DE-AC52-07NA27344

50th Annual Anomalous Absorption Conference
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Developing Predictive Modeling of Laser-Plasma Interactions for X-ray Radiographic Imaging*

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Novel MeV x-ray sources based on high-power short-pulse lasers have the potential to revolutionize radiography with their small spot size, short pulse duration, low cost, and flexibility. Los Alamos National Laboratory has recently embarked on an effort to understand such sources and develop a predictive capability through modeling and experimental campaigns. In this talk, we report on the progress so far of the modeling team and compare predictions to a recently-completed experimental campaign on the Texas Petawatt laser. Using particle-in-cell and Monte Carlo particle-transport codes, we simulate electron acceleration in experiments using plastic, foam, and gold nanorod targets, and calculate photon spectra resulting from bremsstrahlung radiation in a high-Z converter. We discuss challenges of performing predictive simulations and how common figures of merit (e.g. laser absorption fraction) may not directly translate to desired experimental outputs (MeV x-rays).

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

Vacuum laser acceleration of electrons using relativistic transparency injection

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Accelerating charged particles using intense lasers has been an active area of research over the past few decades. Such laser-based compact accelerators have several potential applications including fast ignition, high-energy physics, radiography, and secondary ion/neutron sources. Among several schemes available to accelerate electrons using intense laser, vacuum laser acceleration (VLA) is the simplest scheme where the electrons are directly accelerated by the intense laser field. The grand challenge of VLA lies in how to load free electrons into the fast-varying laser field properly such that the injected electron remains within a given half cycle of the laser wave and sees a unipolar field for continuous acceleration. This requirement necessitates the injected electron to be pre-accelerated close to the speed of light (i.e., the laser speed) before it can be captured and accelerated by the intense laser field. The LANL team has recently demonstrated VLA of electrons up to 20 MeV using an injection method that exploits the plasma relativistic transparency (RT) effect – where dense opaque plasma becomes transparent to the driving laser due to relativistic electron mass increase – by driving a thin solid foil at normal laser incidence [P.K. Singh, F.-Y.Li et al nature Communications 13,54 2022]. When the laser interacts with a thin foil, super-ponderomotive electrons are generated via VLA by using the novel RT effect as the injector. Experiments show 20 MeV super-ponderomotive electrons from thin plastic foils (5 nm thick) undergoing RT injection and subsequent VLA. This work not only solves an outstanding problem in VLA by demonstrating a viable injection method, but also provides insight into the electron acceleration in relativistically transparent plasmas, which serves as the primary driver for laser-foil-based ion accelerators, x-ray sources, and relativistic optics.

Relativistically transparent magnetic filaments: A path to megatesla fields and efficient gamma radiation*

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Relativistic transparency enables volumetric laser interaction with overdense plasmas and direct laser acceleration of electrons to relativistic velocities. The dense electron current driven in the plasma by the ponderomotive force generates a magnetic filament with field strength of the order of the laser amplitude ($>10^5$ T). This magnetic filament traps the electrons radially, enabling efficient acceleration of the electrons by interaction with the laser electric field and conversion of laser energy into MeV photons by electron oscillations in the filament. The use of a microstructured target stabilizes the hosing instability associated with relativistically transparent interactions, resulting in robust and repeatable production of this phenomenon.

In this work we present analytical scaling laws that describe the radiated photon spectrum and energy from the magnetic filament phenomenon in terms of the laser intensity, focal radius, pulse duration, and the plasma density.[1] These scaling laws are compared to 3-D particle-in-cell (PIC) simulations, demonstrating agreement over two regimes of focal radius. Preliminary experiments to study this phenomenon at moderate intensity ($a_0 \sim 20$ to 30) were performed on the Texas Petawatt and OMEGA EP lasers. Experimental signatures of the magnetic filament phenomenon are observed in the electron and photon spectra recorded in a subset of these experiments that is consistent with the experimental design, the analytical scaling, and 3-D PIC simulations. We discuss the prospects for scaling of this phenomenon to higher intensities for laser-driven studies of megatesla fields in plasmas and high-efficiency secondary sources; above 6×10^{21} W/cm^2, laser conversion efficiency into MeV photons is predicted to exceed 10%.

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[1] H.G. Rinderknecht, T. Wang, A. Laso Garcia, G. Bruhaug, M. S. Wei, H. J. Quevedo, T. Ditmire, J. Williams, A. Haid, D. Doria, K. M. Spohr, T. Toncian, and A. Areviev, *"Relativistically transparent magnetic filaments: scaling laws, initial results, and prospects for strong-field QED studies,"* New J. Phys. **23**, 095009 (2021).

Exact analytic solutions yielding flying-focus pulses*

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Spatiotemporal control of laser intensity refers to a class of optical techniques that decouple the motion of an intensity peak from the group velocity. The dynamic intensity peak, or “flying focus,” can travel at any programmable velocity with a near-constant profile over multiple Rayleigh ranges. Assessing the extent to which these features can enhance laser-based applications, requires an accurate description of the electromagnetic-field structure. Here, we present exact analytical solutions to Maxwell’s equations for the electromagnetic fields of a flying focus pulse. The approach combines the complex source-point method, which transforms multipole solutions into beam-like solutions, with the invariance of Maxwell’s equations under a Lorentz transformation. The solutions are generalized for arbitrary polarization or orbital angular momentum. By propagating the fields backwards in space, we find the space–time profile that an optical assembly must produce to realize these solutions in the laboratory. Comparisons with approximate paraxial solutions provide the conditions for which this simpler treatment can be reliably used to model the flying focus.

*This material is based upon work supported by the Department of Energy (DOE) National Nuclear Security Administration under Award Number DE-NA0003856, DOE Fusion Energy Science under Award Number GR507679, the University of Rochester, and the New York State Energy Research and Development Authority.

Nonlinear Thomson scattering with ponderomotive control

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In nonlinear Thomson scattering, a relativistic electron reradiates the photons of a laser pulse, converting optical light to x rays or beyond. While this extreme frequency conversion offers a promising source for probing high-energy-density materials and driving uncharted regimes of nonlinear quantum electrodynamics, conventional nonlinear Thomson scattering has inherent tradeoffs in its scaling with laser intensity. Here, we discover that the ponderomotive control afforded by spatiotemporal pulse-shaping enables novel regimes of nonlinear Thomson scattering that substantially enhance the scaling of the radiated power, emission angle, and frequency with laser intensity. By appropriately setting the velocity of the intensity peak, a spatiotemporally shaped pulse can increase the power radiated by orders of magnitude. The enhanced scaling with laser intensity allows for operation at significantly lower electron energies or intensities.

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Arbitrarily Structured Laser Pulses*

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We present a new class of approximate solutions to Maxwell's equations, known as Arbitrarily Structured Laser (ASTRL) pulses, which generalize flying focus laser pulses. These solutions describe new types of pulses with previously unrealized degrees of controlled structure, including evolving spot-size, angular momentum, polarization, and transverse focal position. Synthesis of such pulses in future experiments may lead to new techniques in laser-plasma interactions, photonics, and microscopy. In addition, the ASTRL description enables PIC simulations of laser-plasma interactions with flying focus pulses through a simple and inexpensive prescription for field initialization; we present the first PIC simulations of LWFA in the self-injection regime driven by flying focus fields.

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Chair: Turnbull		Speaker	Title
7:00P	Plenary	Edwards	Diffractive Plasma Optics for High-Power Lasers
8:30P	Poster		
	P1	Griff-McMahon	Magnetic Field Amplification in Underdense Plasma By Linearly Polarized Intense Laser Pulses
	P2	Brutus	Efficient Volumetric Diffractive Plasma Optics for Controlling High-Intensity Light
	P3	Fasano	Harmonic Generation in Reflection from Plasma Mirrors
	P4	Djordjevic	Transfer learning and multi-fidelity modeling of laser-driven particle acceleration
	P5	Qu	Creating observable QED collective plasma effects
	P6	Montgomery	X-ray Phase Contrast Imaging of Void Collapse in ICF Ablator Materials
	P7	Lezhnin	Focusability in the multi-pump Raman amplification of short laser pulses
	P8	Huang	High-yield and high-angular-fluence neutron generation from deuterons accelerated by laser-driven collisionless shock
	P9	Griffith	Increased Collective QED Signatures Throguh Particle Reflection
	P10	Weichman	Relativistically thermal plasma generation by magnetically assisted direct laser acceleration

Diffractive Plasma Optics for High-Power Lasers*

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Manipulating laser pulses with peak powers higher than ten petawatts requires either prohibitively large conventional optics or new optical materials that are far more resistant to light-driven damage. Plasma offers this robustness but has proven difficult to control with optical precision, and many experiments on plasma optics have fallen short of theoretical expectations due to inhomogeneity, parasitic instabilities, or kinetic effects. Diffractive volume transmission plasma optics, which rely on wavelength-scale modulations of plasma density to controllably diffract a laser pulse, mitigate some of these challenges. Optical quality density modulations can be produced by a pair of interfering pump lasers, which drive, for example, either a spatially varying pattern of ionization[1] or ponderomotive density perturbations. [2] As this modulation pattern is a plasma phase hologram, we can create diffractive plasma lenses,[3] gratings for chirped pulse amplification,[4] or a variety of other optics by changing the pump geometry. These optics rely only on a static density perturbation, so they can be built in regimes that avoid other instabilities or kinetic effects, and the averaging effect of a volume transmission optic makes them relatively resistant to variations of plasma density and temperature.

Using two distinct experimental approaches, field-ionization gratings driven by femtosecond pump pulses and collisional ionization gratings driven by picosecond pulses, we have built plasma transmission gratings that can diffract a femtosecond pulse with high efficiency (up to 60%).[5] These gratings maintain reasonable pointing stability and focal spot quality in the diffracted beam and tolerate probe intensity higher than both solid-state damage thresholds and the required pump intensity. Our results suggest a path using diffractive plasma optics towards the control and generation of ultra-high-power short-pulse laser beams.

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Magnetic Field Amplification in Underdense Plasmas By Linearly Polarized Intense Laser Pulses*

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High-intensity laser pulses (>10^{18} W/cm^2) have been shown to generate and amplify high-strength, quasistatic magnetic fields in plasmas, which persist on ps timescales.[1,2,3] Using 3D particle-in-cell simulations, we demonstrate that a *linearly* polarized, relativistic-intensity laser pulse propagating in an underdense plasma ($n \sim 0.2 n_{\mathrm{cr}}$) can amplify a static magnetic field, directed along laser propagation, by more than an order of magnitude. Axially accelerated electrons in the laser-induced plasma channel produce an azimuthal magnetic field that twists the seed field into a helix. As the hot electrons follow the field line trajectories, the azimuthal component of their current enhances the axial field. As shown in Figure 1, magnetic amplification in this scheme has a strong dependence on plasma density and seed field strength.

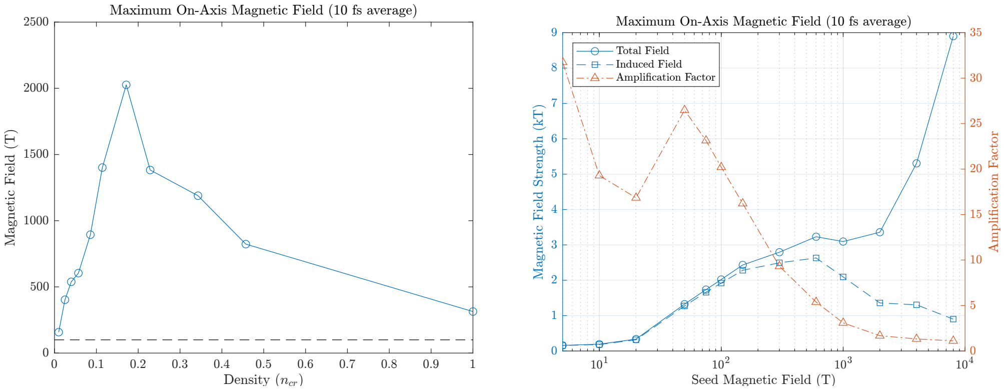

Figure 1: (left) Maximum axial magnetic field as a function of plasma density, normalized to the critical density. (right) Maximum axial magnetic field (blue circles), maximum induced magnetic field (blue square), and amplification factor (red triangle) as functions of seed magnetic field strength.

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50TH ANOMALOUS ABSORPTION CONFERENCE 2022

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Efficiency of Volumetric Diffractive Plasma Optics for Controlling High Intensity Light

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Diffractive plasma optics are proposed high-damage-threshold optics that use structured wavelength-scale plasma modulation to manipulate high-flux laser pulses. These optics are created by interfering pump laser beams to producing a plasma whose density depends on the pump intensity; by varying the geometry of the pumps, we can make plasma lenses, transmission gratings, and other diffractive optics. A delayed probe beam will then be focused or redirected by the plasma. We simulated diffractive lenses and gratings with linear and nonlinear paraxial propagation codes. The focal efficiency of plasma lenses and the diffraction efficiency of plasma gratings were measured under independently varied probe beam wavelength, divergence, and angle of incidence. We show that diffractive lenses can be used across a broad range of pump and probe wavelength combinations. The effective damage thresholds of both structures were determined by characterizing the decrease in optical efficiency for increased probe beam intensity, demonstrating that these optics have much higher damage thresholds than solid materials and allowing us to understand the potential performance and limits of plasma based high-powered laser systems.[1]

[1] This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. This work was supported by LLNL LDRD project 21-LW-013 and partially supported by the DIR-ISS Student Program.

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Harmonic Generation in Reflection from Plasma Mirrors*

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The development of ultrashort pulsed laser systems with peak powers that exceed the damage threshold of conventional solid-state optics has prompted the need to build plasma-based optics. To date, various plasma optics have been developed or proposed for high power laser applications, including plasma mirrors, waveplates, amplifiers, lenses, and gratings. The plasma mirror, in particular, has a broad range of applications for intense light, such as specular reflection and focusing, temporal and spatial cleaning, and generating harmonics. In this work, we report on the effectiveness of using plasma mirrors for harmonic generation with an emphasis on constructing two-color waveforms and generating harmonics with a controlled polarization state. We provide initial demonstration of the use of these unique light sources in further applications by driving harmonic generation in a cascaded plasma mirror configuration.

The experiments were performed using our 20TW Ti:Sapphire laser system (10Hz, 25fs, 400mJ/pulse). The experimental setup features three plasma mirrors operating under two different conditions. The first plasma mirror is driven at sub relativistic intensities and is primarily used to temporally clean the laser of unwanted prepulses, whereas the second two plasma mirrors are driven with relativistic intensities and produce harmonics. The second plasma mirror is used as a two-color waveform synthesizer which can be subsequently refocused onto the final plasma mirror for studying harmonic generation driven by two-color lasers. Characterization of the radiated harmonics is done with spectral and profile measurements of the first four harmonic orders as well as with an extreme ultraviolet spectrometer for higher orders. A quarter-wave plate located before the second plasma mirror allows for converting from linear to circular polarization, and a Wollaston prism is used for determining the polarization state of the emitted harmonics. These sources of secondary radiation are useful for several high-power applications and, in addition, provide insights into the dynamics of relativistically-driven laser produced plasmas.

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50TH ANOMALOUS ABSORPTION CONFERENCE 2022

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Transfer learning and multi-fidelity modeling of laser-driven particle acceleration*

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Computer models of intense, laser-driven ion acceleration require expensive particle-in-cell (PIC) simulations that may struggle tocapture all the multi-scale, multi-dimensional physics involved at reasonable costs. Explored is an approach to ameliorate this deficiency using a physics-informed, multi-fidelity model that can incorporate physical trends and phenomena at different levels. As the base framework for this study, an ensemble of approximately 10,000 1D PIC simulations was generated to buttress separate ensembles of hundreds of higher-fidelity 1D and 2D simulations. Using transfer learning and multi-fidelity modeling in a deep neural network, one can reproduce the results of more complex physics at a much smaller cost. The networks trained in this fashion can in turn act as a surrogate model for the simulations themselves, allowing for quick and efficient exploration of the parameter space of interest. Standard figures-of-merit were used as benchmarks such as the hot electron temperature, peak ion energy, conversion efficiency, etc. in addition to particle energy spectra. These surrogate models are also useful for incorporating more complex schemes, such as pulse shaping. We can rapidly identify and explore under what conditions dimensionality becomes an important effect and search for outliers in feature space.

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Creating observable QED collective plasma effects

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The QED pair plasma regime describes extreme astrophysical environments like magnetars and terrestrial QED experiments where dense electron-positron pairs are generated. But the collective plasma effects are notoriously hard to observe. The pairs are moving at relativistic speeds, making them heavy, which diminishes the plasma frequency and the associated collective effects [1]. However, colliding a relativistic electron beam with a less intense laser creates pairs that have larger plasma frequency, made even larger as they slow down due to the laser pressure [2]. Signatures of collective pair plasma effects in the QED cascades then appear in exquisite detail through plasma-induced frequency upshifts in the laser spectrum. The distinctive features of this signature include a chirp to the frequency upshift as well as parametric dependencies. Recent optimizations show the advantage of using an interferometer or a structured laser beam [3-4]. Because the electron beam and laser technologies are available, this solution to the coupled production-observation problem means that strong-field quantum and collective pair plasma effects can now be explored with existing technology, provided that ultra-dense electron beams are co-located with multi-PW lasers [5-6].

*This work conducted with the support of Grants DENA0003871 and NNSA DE-SC0021248.

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X-ray Phase Contrast Imaging of Void Collapse in ICF Ablator Materials*

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Implosion of a high-convergence inertial confinement fusion (ICF) capsule to achieve ignition requires a smoothly polished ablator that is nearly free of internal voids and defects[1,2]. In addition to seeding hydrodynamic instabilities in the ablator, simulations of such voids show that they can also lead to loss of confinement[3]. In an effort to better understand the dynamics of void collapse under strong shock conditions, experiments were performed at the Linac Coherent Light Source (LCLS) using x-ray phase contrast imaging (XPCI) at 8.2 keV and 18 keV to image individual collapsing voids driven by strong laser shocks in plastic, carbon, and epoxy ablator materials[4,5]. In addition to naturally-occurring voids in CH and carbon, which are often irregular in shape, idealized spherical voids were produced by embedding a 20 - 40 µm diameter SiO$_2$ shell (1-µm thick wall) in a 200-µm slab of SU-8 epoxy. The targets used a 25-µm thick Kapton ablator adhered to the epoxy sample, and were irradiated with a 527-nm laser intensity of ~ 10^{13} W/cm^2, yielding ablation pressures ~ 3 Mbar. 2D simulations using xRAGE indicate that the dynamics of a pure void (no SiO$_2$ shell) behave qualitatively similar to the thin shell void surrogate. We found that 18 keV x-rays were required to observe the collapsing void during shock passage due to the very strong refraction at the shock front for 8.2 keV. High quality XPCI images of the collapsing void dynamics were obtained with ~ 400-nm spatial and 20-fs temporal resolution. Initial experimental results and comparison to 2D xRAGE simulations will be presented.

*This work conducted under the auspices of Los Alamos National Laboratory, managed by Triad National Security LLC, for the National Nuclear Security Administration of the U.S. Dept. of Energy under contract 89233218CNA000001.

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50TH ANOMALOUS ABSORPTION CONFERENCE 2022

50th Annual Anomalous Absorption Conference
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Focusability in the multi-pump Raman amplification of short laser pulses*

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Beam combining is a promising concept for amplification of laser beam via crossing it with multiple pump beams. The ongoing experimental campaign at National Ignition Facility demonstrated the feasibility of generating high power beams by crossing a seed beam with multiple identical pumps. Using coupled nonlinear Schrodinger equation model and 2D particle-in-cell simulations, we investigate the effect of resonant multi-pump amplification on the focusability of the seed beam. We demonstrate that a single pump of finite width creates the amplified pulse that immediately diffracts, losing focusability. The uniformity of the amplified pulse was found to play a crucial role in seed focusability. We test a few methods of improving the uniformity of the seed amplification via (1) widening pump pulse, (2) using multiple pump pulses, or (3) smoothly depositing pump energy through a near-forward beam crossing geometry. Simulations show that these methods could retain or even exceed the focusability of the original Gaussian beam.

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High-yield and high-angular-fluence neutron generation from deuterons accelerated by laser-driven collisionless shock*

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Compact and bright collimated neutron sources have several applications in global security and fundamental scientific research. We study a concept of laser-driven neutron source based on the collisionless shock acceleration of deuterons in a deuterated target and the use of a Beryllium converter in a pitcher-catcher setup[1]. This neutron source concept features small neutron-source size and predominantly forward high energy neutrons that allow penetrability in shielded material. High neutron yield per Joule can be achieved in a short duration with synchronization of the optical driver providing the advantage of spatial and time precision. We discuss the characteristics of the neutron break-up reaction which motivate the choice of the acceleration mechanism, the consideration for the optimization of the laser plasma interactions and the overall scaling of the neutron yield and flux of such concept. In addition, distinction and possible control of the target normal sheath field acceleration will be discussed. The development of such laser-driven neutron sources may enable the design of next generation high precision radiography and global security applications.

* This work was supported by the U.S. Department of Energy through the Los Alamos National Laboratory (LANL). This work was initiated under the LANL LDRD 20180732ER program and continued under OES ADP.

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Increased Collective QED Signatures Through Particle Reflection*

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A time-varying plasma frequency shifts the frequency of any passing laser. In a QED cascade, the plasma frequency changes both when the electron-positron pairs are created and when they are slowed down. The QED cascade thus results in a change of laser frequency, which could serve as a first experimental signature of collective effects in the QED plasma regime.[1] However, generated pairs will have large Lorentz factors, reducing their impact on the laser frequency shift despite the high density. Pair plasma contributions to frequency shifts can be increased through stopping and re-accelerating pair particles.[2] Borrowing from direct laser acceleration we compare using a Laguerre-Gaussian (LG) mode to better re-accelerate generated pairs. The LG mode does not achieve superior re-acceleration when compared against a fundamental Gaussian mode in our simulations. However, the transverse structure of the LG mode results in longer interactions between the laser and the pair particles which can allow for increased pair plasma density accumulation.

*This work conducted with the support of Grants DENA0003871 and NNSA DE-SC0021248.

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Relativistically thermal plasma generation by magnetically assisted direct laser acceleration*

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We introduce the first approach to volumetrically generate relativistically thermal plasma at gas-jet–accessible density. Using fully kinetic simulations and theory, we demonstrate that two stages of direct laser acceleration driven by two laser pulses in an applied magnetic field can heat a significant plasma volume to multi-MeV average energy. The highest-momentum feature is 2D-isotropic, persists after the interaction, and includes the majority of electrons, thereby enabling experimental access to bulk-relativistic, high-energy-density plasma in an optically diagnosable regime for the first time.[1]

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0003856, the University of Rochester, and the New York State Energy Research and Development Authority, and the DOE Office of Science under Grant No. DESC0018312. A.V.A. was supported by NSF Grant No. 1903098. The support of DOE does not constitute an endorsement by DOE of the views expressed in this abstract. Particle-in-cell simulations were performed using EPOCH, developed under UK EPSRC Grant Nos. EP/G054940, EP/G055165, and EP/G056803. This work used HPC resources of the National Energy Research Scientific Computing Center (NERSC), a U.S. Department of Energy Office of Science User Facility operated under Contract No. DE-AC02-05CH11231, and the Extreme Science and Engineering Discovery Environment (XSEDE), which is supported by National Science Foundation grant number ACI-1548562, under allocation TG-PHY190034 on the Texas Advanced Computing Center (TACC) at The University of Texas at Austin.

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Agenda

Wednesday, June 8

Cross Beam Energy Transfer			
Chair: Palastro		Speaker	Title
8:30A	Invited	Nguyen	Cross-beam energy transfer saturation by ion-trapping-induced detuning
9:00A	Oral	Seaton	Theory and simulation of cross-beam energy transfer mitigation through increased laser bandwidth
9:20A	Oral	Yin	Nonlinear cross-beam energy transfer model for ICF/HED design codes
9:40A	Oral	Edgell	Polarization-smoothing-induced nonuniformity in direct-drive implosions on OMEGA
10:00A	Break		
Instabilities			
Chair: Colaitis			
10:30A	Invited	Milder	Direct measurement of the return current instability
11:00A	Oral	Rousseaux	Experimental evidence of enhanced density fluctuations in plasmas experiencing stimulated Raman scattering of picosecond and nanosecond laser pulses
11:20A	Oral	Myatt	Stimulated Raman side scattering--important at last!
11:40A	Oral	Rovere	Scaling of hot electron generation from two-plasmon decay instability
12:00P	Oral	Solodov	Hot-electron preheat and mitigation in polar-direct-drive experiments at the National Ignition Facility
12:20P			Business Meeting
12:30P	Lunch		
2:00P	Archery Tag (Group Game)		Please let Raka know if you want to join this group activity at registration.
6:00P			Group Photo
6:30P			BBQ Dinner

Cross-beam energy transfer saturation by ion-trapping–induced detuning*

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The performance of direct-drive inertial confinement fusion (ICF) implosions relies critically on the coupling of laser energy to the target plasma. Cross beam energy transfer (CBET), the resonant exchange of energy between intersecting laser beams mediated by ponderomotively driven ion-acoustic waves (IAW), inhibits this coupling by scattering light into unwanted directions. The variety of beam intersection angles and varying plasma conditions in an implosion result in IAWs with a range of phase velocities. Here we will show that, for the plasma conditions of Tunable OMEGA Port 9 (TOP9) experiments at the Laboratory for Laser Energetics, CBET saturates through a resonance detuning that depends on the IAW phase velocity and that arises from trapping-induced modifications to the ion distribution function[1,2]. For smaller phase velocities, the modifications to the distribution function can rapidly thermalize, leading to a blueshift in the resonant frequency. For larger phase velocities, the modifications can persist, leading to a redshift in the resonant frequency. We will also present preliminary results of vector particle-in-cell (VPIC) simulations for CBET in conditions relevant to an ICF implosion at the OMEGA laser facility. Ultimately, these results may reveal pathways towards CBET mitigation and inform reduced models for radiation hydrodynamics codes to improve their predictive capability.

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[2] Nguyen, Khanh Linh, et al. "Cross-beam energy transfer saturation by ion trapping-induced detuning." Physics of Plasmas 28.8 (2021): 082705.

Theory and simulation of cross-beam energy transfer mitigation through increased laser bandwidth*

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Recently, techniques have been proposed to increase laser bandwidth in inertial confinement fusion (ICF) implosions. These bandwidths could provide transformational improvements in ICF performance by mitigating laser-plasma and hydrodynamic instabilities. This talk will examine the impact of bandwidth on the cross-beam energy transfer (CBET) instability. A generalized linear theory for CBET will be presented that incorporates effects of bandwidth[1]. This is compared with data from linearized fluid simulations performed with the LPSE code, which satisfy many of the assumptions made by the theory and shows good agreement with the theoretical predictions. Particle-in-cell simulations of CBET using the VPIC code have also been performed, allowing an investigation of the nonlinear CBET regime.

It is found that CBET is most effectively suppressed when laser bandwidth exceeds the ion-acoustic wave (IAW) frequency. Such bandwidths reduce the coupling efficiency of laser beams with IAWs and can allow reverse (from lower frequency to higher frequency beams) transfer to occur, which reduces the net energy transfer rapidly as bandwidth is increased. The CBET gain exponent in this regime scales with bandwidth ($\Delta\omega$) as $\Delta\omega^{-3}$ for Gaussian or Lorentzian laser spectra. However, linear analysis also finds that the IAW energy density scales as $\Delta\omega^{-1}$, implying that nonlinear effects may be more difficult to control than the CBET scaling would suggest. Indeed, ion-trapping-induced nonlinear effects, such as modification of the ion wave dispersion, the two-ion wave decay, and ion wave self-focusing, lead to significant departures from linear theory[2]. These nonlinearities can be mitigated through the reduction of intensity spikes in the laser drive, for example via smoothing by spectral dispersion.

*This work conducted under the auspices of the US Department of Energy by the Triad National Security, LLC Los Alamos National Laboratory

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Nonlinear cross-beam energy transfer model for ICF/HED design codes*

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Cross-beam energy transfer (CBET) allows crossing laser beams to exchange energy and is critically important for ICF/HED experiments. The nonlinear physics of CBET for multi-speckled laser beams is examined using particle-in-cell simulations for a range of plasma conditions, laser intensities, and crossing angles relevant to indirect-drive ICF experiments. The time-dependent growth and saturation of CBET involve complex, nonlinear ion and electron dynamics, including ion trapping-induced enhancement and detuning, ion acoustic wave (IAW) nonlinearity, oblique forward stimulated Raman scattering (FSRS), and backward stimulated Brillouin scattering (BSBS) in a CBET-amplified seed beam. Ion-trapping-induced detuning of CBET is captured in the kinetic linear response by a new δf-Gaussian-mixture algorithm, enabling an accurate characterization of trapping-induced non-Maxwellian distributions. Nonlinear effects lead to deviation of CBET gain from linear theory based on a single-Maxwellian distribution. Ion trapping induces nonlinear processes such as changes to the IAW dispersion and nonlinearities (e.g., bowing and self-focusing), which, together with pump depletion, FSRS, and BSBS, determine the time-dependent nature and level of CBET gain as the system approaches steady state. Using VPIC nonlinear simulations, we construct a nonlinear CBET model that computes the nonlinear CBET gain (including effects from ion trapping and secondary instabilities) from local quantities such as plasma density and laser intensity, the IAW wavenumber $k\lambda_D$, and the electron-to-ion temperature ratio T_e/T_i.

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* This work was supported by the Los Alamos National Laboratory Directed Research and Development (LDRD) Program. VPIC simulations were run on LANL Institutional Computing Clusters.

Polarization-smoothing–induced nonuniformity in direct-drive implosions on OMEGA*

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A growing body of evidence, including core flow, ion-temperature asymmetry, and scattered-light distribution, suggests that OMEGA implosions are less uniform than standard predictions. The measurements of the intensity of unabsorbed light from nominally symmetric implosions show large variation, on the order of tens of percent rms, about the target chamber. The measurements come from multiple different scattered-light diagnostics and cannot be explained by cross-beam energy transfer (CBET) between symmetric beams. The scattered-light nonuniformity has been found to be due to a previously unrealized source of asymmetry in each beam—the polarization smoothing scheme used on OMEGA to reduce laser speckle.

On OMEGA, each beam is split into two nearly co-propagating beams with orthogonal polarizations using a distributed polarization rotator (DPR). On target, the focal spots of these two beams are offset by ~90 μm, producing two nonoverlapping copies of each beam's speckle pattern each with half the original speckle intensity. While this ensures the orthogonal polarizations are balanced within the center of each beam, areas near the edge remain linearly polarized because of the far-field offset. Due to the strong polarization dependence of CBET, each OMEGA beam exchanges a different amount of energy in the linear edge regions depending on the alignment of their polarizations and the direction of each offset.

Fully 3-D CBET modeling of the DPR-induced polarization for each OMEGA beam has shown that this effect can explain the observed scattered light nonuniformity on OMEGA.[1] This beam asymmetry also increases the overall absorption nonuniformity and may decrease implosion performance. When the measured beam balance and beam mispointing are included along with the DPR polarization in 3-D CBET modeling, the absorption mode 1 is well aligned with the core-flow direction measured for implosions. These results suggest that fully 3-D CBET hydrodynamic modeling may be valuable in furthering direct-drive implosion performance.

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

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Direct measurement of the return current instability*

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Heat transport is a topic of fundamental importance to all of plasma physics. Many transport models are based on the seminal work of Spitzer and Harm, however this model nearly always requires ad hoc corrections to reproduce experimental observables. These discrepancies are related to the failure of the local transport relations and indicate a need for the kinetic description of the particle transport. In a plasma where the heating is localized, heat carrying electrons travel down the temperature gradient, generating a current that is neutralized by a cold return current. When the return current is large enough the electrons begin to transfer energy into the ion-acoustic waves, becoming absolutely unstable and growing in time. This return current instability drives a broad turbulent spectrum of ion acoustic waves that are predicted to limit the return current, inhibit heat transport, modify laser absorption, and alter the fluctuation spectrum from which other ion instabilities grow.

Here, we present measurements of the ion-acoustic growth rate driven by the return current instability and show it is inherently connected to non-local transport. Thomson scattering was used to measure a maximum growth rate of 5.1×10^{9} Hz, which was three times less than classical Spitzer-Harm theory predicts. The measured plasma conditions suggest that the electrons are non-local and Vlasov-Fokker-Plank (VFP) simulations that account for this non-locality reproduce the measured growth rates. Furthermore, the threshold for the return current instability was measured ($\delta_T = \lambda_{mfp}/L_T = 0.016 \pm 0.002$) to be in good agreement with previous theoretical models.

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Experimental evidence of enhanced density fluctuations in plasmas experiencing stimulated Raman scattering of picosecond and nanosecond laser pulses

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Experiments performed at LULI's ELFIE laser facility demonstrated that the threshold and saturation level of backward stimulated Raman scattering (B-SRS) in a relatively weak-intensity picosecond laser speckle can be affected by a neighboring stronger-intensity speckle over distances of several tens of microns [1, 2]. Such a coupling was attributed to enhanced electrostatic fluctuations excited by suprathermal electrons, produced as a result of the damping of the nonlinear electron plasma waves (EPWs) driven through B-SRS in the strong speckle.

Here we report on further evidence of the generation of anomalously intense and broadband density fluctuations in two recent laser-plasma experiments, employing either single picosecond (SPB) or multiple nanosecond (MNB) laser beams. Both experiments made use of multicolor Thomson probe diagnostics in preformed He gas jet plasmas. In the MNB experiment, performed at the LULI2000 facility, the electron and ion density fluctuations were measured at different angles relative to the laser drive direction and at wavenumbers significantly larger than those associated with B-SRS or backward stimulated Brillouin scattering (B-SBS). In the presence of B-SRS, the Thomson signals corresponding to the electron (resp. ion) fluctuations were found to be amplified by a factor larger than 50 (resp. 1000). In addition, and quite unexpectedly, strong electron density fluctuations at twice the plasma frequency were consistently detected.

The SPB experiment, the last ever to be carried out at the ELFIE facility, aimed at characterizing these nonstandard plasma fluctuations with unprecedentedly high spatiotemporal resolution. A major finding was the detection of ion acoustic waves (IAWs) distinct from those expected from B-SBS or from the usual secondary plasma parametric instabilities, and the correlation of these IAWs with the occurrence of B-SRS at earlier times. Their lifetime (or damping time) was characterized as a function of the plasma density and laser intensity.

Possible scenarios accounting for those results will be discussed, in which suprathermal electrons are thought to play the major role.

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Stimulated Raman side scattering - important at last!*

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During the early history of the Anomalous Absorption Conference, theoretical calculations pointed to the stimulated Raman side scattering (SRSS) instability as an important loss and preheat mechanism in directly driven inertial confinement fusion (ICF). However, over the intervening years, no evidence of SRSS has been seen in directly-driven 60 beam OMEGA implosions (or indeed, SRS of any kind for typical cryogenic implosions). However, more recent long-scale-length spherical target experiments, performed on the OMEGA EP laser[1], and results obtained on the National Ignition Facility (NIF)[2] have changed this picture: The NIF experiments have shown SRSS to be an energetically important process, possibly responsible for the observed hot electron generation. As will be described, a new model, based on generalized ray tracing[3] is shown to explain the time-dependent scattered light spectra from the OMEGA EP experiments: it identifies SRSS and near backscatter from portions of each incident beam where the scattered electromagnetic wave is generated in a direction parallel to iso-density contours. This is shown to be the result of the relatively high single beam intensities used in the experiments (relative to 60-beam OMEGA), showing that its importance is not restricted to high temperature, MJ-scale, plasmas. The nature of SRSS instability (temporal versus spatial growth) is discussed as are the conditions when the absolute instability is expected to be important. It is further suggested that the OMEGA EP platform could provide a good surrogate in which to develop SRSS mitigation strategies and to finally test the applicability of the early theories.

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Scaling of hot electron generation from two plasmon decay instability

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Hot electrons (HE) are a key component for Inertial Confinement Fusion (ICF), in particular for fuel pre-heat concerns[1], which can negatively impact the target's fusion yield. Laser plasma instabilities (LPIs) that occur in the coronal plasma are responsible for HE generation; an example common to OMEGA and sub ignition pulses is Two Plasmon Decay (TPD), a type of LPI where an electromagnetic wave decays into two electron plasma waves (EPWs)[2]. Electrons can acquire high energies through Landau damping of EPWs that are trapped and subsequently amplified by a collapsing caviton[3], or by staged acceleration caused by several EPWs at increasingly high phase velocities[4].

Understanding how plasma and laser parameters dictate hot electron generation is an important step for proposing robust and credible ICF designs. Ultimately, hydrodynamic codes should include the generation and propagation of HEs from LPIs. To that end, we conduct a parametric study of HE generation through the use of the hybrid simulation code Laser Plasma Simulation Environment (LPSE)[5], to model HE generation in a parameter space of laser and plasma conditions, from which common HE quantities and behaviors have been investigated. The data will then be used as input parameters for macroscopic systems in hydrodynamic codes simulations.

We present an investigation of absolute TPD in 2D, in the presence of the saturation processes of Langmuir Decay Instability (LDI) and laser pump depletion. A scaling analysis of HE conversion fraction, temperature, transmission and angular distribution has been performed, depending on the parameters T_e , T_i /T_e , I/I_{thr}^{TPD} and L_n , over a set of 240 LPSE simulations. A preliminary investigation of the introduction of SRS in the system and its competition with TPD for the laser energy, will also be presented.

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Hot-electron preheat and mitigation in polar-direct-drive experiments at the National Ignition Facility*

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Target preheat by super-thermal electrons from laser–plasma instabilities is a major challenge for direct-drive inertial confinement fusion. Polar-direct-drive (PDD) surrogate plastic implosion experiments were performed at the National Ignition Facility (NIF) to quantify preheat levels at ignition-relevant scale and develop mitigation strategies.[1] The experiments were used to infer the hot-electron temperature, energy fraction, divergence, and to directly measure the radial hot-electron energy deposition profile inside the imploding shell. This was achieved employing mass-equivalent plastic targets with inner Ge-doped layers and comparing the measured hard x-ray and Ge-K_α spectra to simulations of the target implosion, electron transport, and x-ray emission. The hot-electron coupling to the unablated shell was found to increase from 0.2% to 0.6% of the laser energy when the incident laser intensity was increased from 0.75 to 1.25×10^{15} W/cm^2, with half of the preheat coupled to the inner 80% of the unablated shell. It is shown that a thin mid-Z Si layer buried in the ablator or a Si-doped outer layer strongly mitigate stimulated Raman scattering, which is responsible for hot-electron generation at direct-drive ignition-relevant conditions. The preheat is effectively suppressed using a Si layer at intensity of 7.5×10^{14} W/cm^2 and reduced by a factor of ~2 at higher intensities. This provides a promising hot-electron preheat-mitigation strategy that can expand the ignition design space to higher intensity. These preheat levels have been extrapolated to the future cryogenic DT, ignition-scale PDD implosions on the NIF, showing that hot-electron preheat can be acceptable for on-target intensities close to 10^{15} W/cm^2.

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

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[1] A. A. Solodov, M. J. Rosenberg, M. Stoeckl, A. R. Christopherson, R. Betti, P. B. Radha, C. Stoeckl, M. Hohenberger, B. Bachman, R. Epstein, R. K. Follet, W. Seka, J. F. Myatt, P. Michel, S. P. Regan, J. P. Palastro, D. H. Froula, E. M. Campbell, and V. N. Goncharov, *"Hot-Electron Preheat and Mitigation in Polar-Direct-Drive Experiments at the National Ignition Facility,"* submitted to Physical Review Letters.

Agenda

Thursday, June 9

Magnetized plasmas			
Chair: Strozzi		Speaker	Title
8:30A	Invited	Vogman	A two-species quasilinear model for current-carrying magnetized plasmas and its validation using continuum kinetic simulations
9:00A	Oral	Winjum	Parameter scan of stimulated Raman scattering in magnetic fields
9:20A	Oral	Lee	Effect of small normalized magnetic fields on rescatter of stimulated Raman scattering in the kinetic regime
9:40A	Oral	Reichelt	Influence of Self-Generated Fields on Hot Electron Transport in NIF Hohlraums
10:00A	Break		
Alternative implosion platforms			
Chair: Olson			
10:30A	Invited	Sio	Progress on magnetized indirect-drive implosions at the National Ignition Facility
11:00A	Oral	Strozzi	Modeling the first Magetized NIF Hohlraum Implosions
11:20A	Oral	Moody	The magnetized indirect drive implosion project on NIF
11:40A	Oral	Pearcy	ARES Simulations of Inverted Corona Experiments at the OMEGA Laser Facility
12:00P	Oral	Sauppe	Uncovering 3D Features in Cylindrical Implosion Experiments using the FLASH Code
12:30P	Lunch		

A two-species quasilinear model for current-carrying magnetized plasmas and its validation using continuum kinetic simulations*

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Collisionless plasmas in pulsed power inertial confinement fusion experiments cause unpredictable power flow and degrade performance. These plasmas are strongly influenced by nonlinear kinetic physics, which is difficult to characterize and which leads to anomalous resistivity and heating. To understand and quantify how microphysics governs macroscopic properties, a self-consistent closed-form quasilinear (QL) theory analysis is developed and validated using state-of-the-art fourth-order accurate continuum kinetic simulations. The QL model describes a fully-kinetic two-species current-carrying magnetized plasma while fully encapsulating ion and electron gyromotion. The QL system of equations -- which couples velocity-space diffusion equations for electron and ion distribution functions, the electric field energy evolution equation, and the dispersion relation -- are solved numerically and self-consistently, without invoking commonly-used asymptotic and/or Maxwellian approximations. The QL model is validated against nonlinear noise-free Vlasov-Poisson simulations of a two-species low-beta plasma undergoing the lower hybrid drift instability. The QL predictions are shown to be consistent with multiple aspects of the simulations. The theoretical and computational study demonstrates progress toward a validated description of the nonlinear saturated state of current-carrying plasmas and provides bounds on the degree to which QL theory can predict "anomalous" properties. LLNL-ABS-833752

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Parameter scan of stimulated Raman scattering in magnetic fields*

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We show particle-in-cell simulations and experimental results that illustrate how weak magnetic fields ($\omega_c/\omega_p << 1$) impact stimulated Raman scattering (SRS) in the kinetic regime ($k\lambda_D \approx 0.3$). Our previous work demonstrated that SRS can be mitigated by weak magnetic fields due to the damping of electron plasma waves (EPWs) propagating perpendicular to the magnetic field.[1] Magnetic fields can also interfere with the nonlinear frequency shift of SRS-driven EPWs, and for SRS that is dominated by the dynamics of this frequency shift, magnetic fields can thereby indirectly enhance the frequency resonance between the light and plasma waves involved in SRS. Furthermore, in some parameter regimes, the SRS waves can themselves be unstable (e.g. the backscattered light wave can decay via rescatter and the backscattered EPW can decay via LDI), and for finite-width waves in multi-dimensions, the damping and transverse evolution of SRS EPWs depends sensitively on wave-particle interactions that can be impacted by magnetic fields. We illustrate how magnetic fields impact SRS and EPWs across a range of laser and plasma parameters.

*This work was supported by DOE NNSA DE-NA0003842 and FES DE-SC0019010.

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[1] B. J. Winjum, F. S. Tsung, and W. B. Mori, Phys Rev E **98**, 043208 (2018).

Effect of small normalized magnetic fields on rescatter of stimulated Raman scattering in the kinetic regime*

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We have previously shown [1] how backward stimulated Raman scattering (SRS) in the kinetic regime ($k\lambda_{De} \approx 0.30$ for backward SRS scattered plasma wave) can be mitigated by weak magnetic fields ($\omega_c/\omega_p << 1$). In this presentation, we show results of 1D and 2D OSIRIS simulations of SRS in the kinetic regime for unmagnetized and magnetized plasmas at densities low enough ($n_e/n_c < 11\%$) such that rescatter (backscattered light wave itself backscatters) is possible. We show that for these parameters, the magnetic field can enhance time averaged reflectivity of backward SRS by modifying plasma conditions and suppressing rescatter.

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

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

Influence of Self-Generated Fields on Hot Electron Transport in NIF Hohlraums

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In ICF hohlraums, high laser intensities drive multiple types of instabilities capable of accelerating electrons to supra-thermal velocities. These hot electrons interact with the hohlraum plasma and walls to produce hard x-ray bremsstrahlung emission that can be seen in various diagnostics like NIF's FFLEX. Hot electrons in the hohlraum can be confined by spontaneously generated magnetic fields within the hohlraum plasma and result in x-ray spectra with features that give information about the evolution of magnetic and electric fields within the hohlraum. Dewald et al. [1] have shown that for low gas fill hohlraums during the picket pulse, electrons are deposited as though they were emitted in a beaming configuration. In this work, we develop a model to consider the influence of self-generated electromagnetic fields on the transport of electrons in order to explain anomalous phenomena seen by Dewald et al. as well as new time resolved spectral information.

* This work was supported by DOE/NNSA contract DE-NA0003868; B. Reichelt is supported by NNSA SSGF DE-NA0003960

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[1] E. L. Dewald et al, "*Generation and Beaming of Early Hot Electrons onto the Capsule in Laser-Driven Ignition Hohlraums,*" PRL **116**, 075003 (2016).

Progress on magnetized indirect-drive implosions at the National Ignition Facility*

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Magnetized fuel offers a potentially transformational way to boost the yield of current indirect-drive implosion designs on NIF by a factor of 2 or more and opens the door to new designs specifically tailored for use with a B-field. The NIF program at LLNL has an ongoing project to install the infrastructure needed to test the performance improvement of magnetizing the DT fuel in cryo-layered indirect-drive implosions, and plans to start magnetized layered implosions in 2024. The first set of magnetized NIF implosions completed during 2021 tested the performance improvement in a room-temperature D_2-filled HDC capsule in a 540-scale $AuTa_4$ (high-electrical-resistance) hohlraum. The measurements showed that applying a 26-T axial B-field boosted the hot-spot temperature by 40% from 2.7 keV to 3.8 keV and amplified the DD yield by a factor of 2.9x. In addition to the primary DD yield and temperature increase, the secondary DT yield is used to estimate the compressed B-field in the hot spot. At sufficiently high B-field, the 1.0-MeV DD-t from the DD reactions can be magnetically confined in the hot spot, increasing their energy loss and probability to undergo a secondary DT fusion reaction (increasing the secondary yield ratio Y_{DT}/Y_{DD}). Within the assumptions made by our model, the burn-averaged B-field in the hot spot is estimated to be $B = 4.7 \pm 1.3$ kT, in good agreement with the LASNEX-simulated B-field at stagnation.

*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 20-SI-002.

Modeling the First Magnetized NIF Hohlraum Implosions*

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We have successfully performed seven hohlraum-driven implosions on the NIF "magnetized warm platform[1]", with imposed magnetic fields in the capsule between 0 and 26 Tesla (see talks by H. Sio and J. Moody at this meeting). These room-temperature shots use a high resistivity AuTa4 alloy hohlraum to reduce eddy currents[2] and a gas-filled diamond capsule with a laser pulse based on the BigFoot[3] design. We have modeled these shots with the radiation-magneto-hydrodynamic (rad-MHD) code Lasnex[4] and the Lasnex Hohlraum Template (LHT) common model[5]. In hohlraum simulations, multipliers on the total laser power (the so-called "drive deficit") and cone fraction (ratio of inner to total beam power) were developed using the Automated NIF Tuning Suite (ANTS) [6] to match the observed time of peak capsule emission and shape of the hotspot x-ray image. The values are similar to those needed for comparable BigFoot shots, and show the drive deficit does not vary much with imposed field. We are exploring the role of crossed-beam energy transfer (CBET) on shape in this platform, and any effect of the imposed field on it.

With laser multipliers to match implosion bangtime and shape, we consider the resulting fusion yield and ion temperature. These agree well with data for comparable BigFoot shots, but less well for the magnetized warm platform. Namely, modeling is fairly close to the measured ion temperature and correctly captures its ~1.1 keV increase due to an imposed 26 T field. The simulated yield is higher than measured by factors of several, with a *larger* discrepancy for shots with no imposed field. Potential causes for the worse modeling of the magnetized warm vs. Bigfoot platform include the AuTa4 vs. pure Au wall, a low-power "caboose" at the end of the laser pulse (due to SBS risk) and resulting longer "coast time," a lower capsule gas fill density, and differences in the capsule fill tube perturbation or net hotspot velocity. The *relative* increase in yield is similar in modeling (2.4x) and data (2.9x).

Overall, we believe our Lasnex rad-MHD model can be used to design future magnetized indirect-drive experiments, though resolving the excess yield would certainly increase confidence.

* 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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[3] C A Thomas, E M Campbell, K L Baker, D T Caser, M Hohenerger et al., Phys Plasmas **27**, 112708 (2020).
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[5] O S Jones, L J Suter, H A Scott, M A Barrios, W A Farmer et al., Phys Plasmas **24**, 056312 (2017).
[6] C R Weber, LLNL, private communication (2022).

The magnetized indirect drive implosion project on NIF*

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Magnetizing the fuel in ICF implosions offers a potentially transformational way to boost the performance of many different target designs. The magnetized indirect drive implosion project on NIF involves developing a new high electrical resistivity hohlraum material, a pulser system to generate the B-field, DT ice layering development and NIF experiments. This talk will describe the science and technology challenges involved in this project. In addition, we will discuss some of the experiments we are currently doing on the Omega laser to explore the physics of magnetized HED which is relevant to magnetized implosions.

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ARES Simulations of Inverted Corona Experiments at the OMEGA Laser Facility

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Inverted corona experiments, wherein lasers are focused onto the inside walls of a capsule lined with deuterated plastic (CD), are a promising candidate for use as neutron sources in laser experiments. While such targets are expected to achieve significant yields at NIF energy scales, the effects of specific target design elements (such as liner thickness) on yield are not yet well-understood and-characterized. ARES is a massively parallel, multi-dimensional, multi-physics code developed and maintained by Lawrence Livermore National Laboratory (LLNL). In this study, we used ARES' well-established and benchmarked molecular diffusion and dynamic mixing packages to investigate the effect of diffusion and mix on neutron yield, and to compare simulated results with an experiment performed at OMEGA exploring the effect of CD liner thickness on neutron yield in DD and ^{3}He filled inverted corona targets. We found that while ARES overpredicts the neutron yields by roughly a factor of 10, its predictions of yield scaling with liner thickness closely match those experimentally observed.

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Uncovering 3D Features in Cylindrical Implosion Experiments using the FLASH Code*

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Directly driven cylindrical implosion experiments are ongoing to measure convergent hydrodynamic instability growth in the high energy density (HED) regime relevant to inertial confinement fusion, as they include the Bell-Plesset effects of convergence while retaining direct diagnostic access. The radiation-hydrodynamics code xRAGE[1,2] has been used to model these systems, and it was instrumental in designing experiments demonstrating scale-invariant instability growth between cylinders fielded at the OMEGA laser facility and the National Ignition Facility (NIF). Recent NIF experiments manifest a clear m=8 azimuthal asymmetry under multiple distinct drive configurations and target sizes. This effect was not predicted by our xRAGE simulations, which are restricted to two-dimensions (2D) due to current limitations of the laser raytracing module.

We present recent 3D simulations utilizing the FLASH[3,4] radiation-hydrodynamics code that predict an m=8 asymmetry that is in agreement with experimental observations and provides a more complete understanding of the drive imbalance in our cylindrical implosions. FLASH has a fully functioning 3D laser ray-trace capability and is widely used in the design of many different laser-driven HED systems. FLASH simulations demonstrate that the asymmetry arises from differential absorption of the 45- and 50-degree beams used to drive these targets. Importantly, there is a north/south skew as a direct result of the geometry of the NIF beams which is obscured in radiographs viewing down the cylinder axis. We discuss recent experimental results showing control over the m=8 asymmetry by increasing the power in the 45-degree beams to partially offset their reduced coupling efficiency, in agreement with FLASH simulations. [LA-UR-22-23892]

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

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Chair: **P. Michel**		Speaker	Title
7:00P	Plenary	Bates	Suppressing parametric instabilities in direct-drive inertial-confinement fusion plasmas using broadband laser light
8:30P	Poster		
	P1	Wen	Mitigation of inflationary stimulated Raman scattering with laser bandwidth
	P2	Chase	Stimulated Raman backscatter in the kinetic regime of lasers with orbital angular momentum
	P3	Lee	Porting the particle-in-cell code OSIRIS to GPU-accelerated architectures
	P4	Rozmus	Bow shock formation in a plasma flowing across randomized laser beams
	P5	Joglekar	Unsupervised Discovery of Non-Linear Plasma Physics using Differentiable Kinetic Simulations
	P6		
	P7	Barfield	Measurements of anisotropic electron temperatures in magnetized gas-jet plasmas
	P8	Johnson	Experimental observation of the transition from electrostatic toward electromagnetic collisionless shocks in laser-driven plasmas
	P9	Leal	Modeling laser-driven ablative magnetothermal instability
	P10	Shaffer	An extended Vlasov-Fokker-Planck approach to laser absorption and ponderomotive transport effects

Suppressing parametric instabilities in direct-drive inertial-confinement-fusion plasmas using broadband laser light*

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It has long been recognized that laser light with a large bandwidth ($\gtrsim$ 10 THz) has the potential to control parametric instabilities in inertial-confinement-fusion (ICF) plasmas. None of the solid-state or gas lasers used in contemporary ICF experiments, though, has sufficient bandwidth to directly suppress any of the three predominant instabilities that presently impair direct-drive implosions, namely, cross-beam energy transfer, two-plasmon decay and stimulated Raman scattering. In this talk, we present selected numerical simulations of these instabilities and explore the efficacy of large laser bandwidths for their mitigation. We also discuss various experimental approaches that are currently being investigated for increasing the bandwidth of next-generation ICF drivers. These include: 1.) the FLUX laser at the University of Rochester; 2.) the argon fluoride laser (which, in addition to a large native bandwidth, possesses an ultra-short 193-nm wavelength that will help to suppress parametric instabilities even further) at the U.S. Naval Research Laboratory (NRL); and 3.) the stimulated-rotational-Raman-scattering technique, which is also being developed at NRL and might provide a viable means of significantly broadening the bandwidth of green laser light for use in experiments on the National Ignition Facility. The effective suppression of laser-plasma instabilities with broadband lasers would have an enormous impact on the field of ICF because it would allow the use of thicker, lower-aspect-ratio pellets that are more resistant to hydrodynamic instabilities and therefore require less precision in their fabrication and laser illumination uniformity to achieve high-yield implosions.

*This work conducted under the auspices of the U.S. DOE/NNSA

Mitigation of inflationary stimulated Raman scattering with laser bandwidth *

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

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Stimulated Raman backscatter in the kinetic regime of lasers with orbital angular momentum*

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Stimulated Raman scattering (SRS) is a fundamental process in the field of the nonlinear optics of plasmas. This has been actively investigated because it results in deleterious consequences for laser driven inertial confinement fusion (ICF.) SRS of the incoming light interferes by decreasing laser energy coupling to the target and affecting the symmetry of the drive. The linear and nonlinear damping rates of the SRS-driven plasma waves affect the growth rate of SRS in high energy density plasmas where the $k\lambda_D$ of the plasma wave is large. There has been little research on SRS for general Laguerre Gaussian (LG) lasers which can have orbital angular momentum (OAM.) A given laser can scatter into a variety of different OAM modes and the resulting plasma waves can also carry OAM. We present preliminary results of SRS of laser modes with and without OAM for plasma conditions of interest to ICF using the codes pF3D and OSIRIS. We also investigate Raman amplification of a seed pulse for combinations of pumps and seeds with different or the same OAM and compare to the case with no OAM.

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Porting the particle-in-cell code OSIRIS to GPU-accelerated achritectures*

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Furthering our understanding of many of today's interesting problems in plasma physics requires large-scale kinetic simulations using particle-in-cell (PIC) codes. However, these simulations are extremely demanding, requiring that contemporary PIC codes be designed to efficiently use a new fleet of exascale computing architectures, which are increasingly GPU based. We discuss the implementation of a GPU algorithm for the PIC code OSIRIS [1,2]. Development is currently ongoing, and a limited feature production code based on *CUDA C* is nearly complete. The algorithm is being built on the same data structure used to implement dynamic load balancing in OSIRIS [3], which is now part of the developer's release of the code. Maximal memory utilization is critical for performance on GPUs, so dynamic load balancing will be a critical part of a performant and robust GPU-based particle-in-cell code. This is because dynamic load balancing is essential to maintaining maximum memory utilization on real-world problems with severe particle load imbalance such as plasma-based acceleration. Furthermore, we make use of a pre-allocated memory pool to avoid unnecessary buffer reallocation while still allowing the code to run close to, but not exceed, maximum memory utilization.

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Bow shock formation in a plasma flowing across randomized laser beams

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High energy lasers interacting with flowing plasmas can produce a plasma response that leads to beam bending and, by momentum conservation, to slowing down of the plasma flow velocity [1]. For the incoming plasma flow, with a velocity slightly greater than sound speed, the plasma response to a ponderomotive force exerted by speckled laser beams is the strongest, such that slowing down of the flow leads to the formation of a shock. We present hydrodynamic simulations of plasma flow about speckled laser beams that demonstrate shock formation. Linearized theory of the plasma penetration length across a laser beam that is necessary to achieve subsonic flow velocity is confirmed in simulations. A cumulative effect of many speckles produces shock propagating first across the laser beam that emerges next from the speckled laser beam and freely propagates upstream with the velocity and jumps of the flow velocity and density that satisfy Rankine-Hugoniot relations. Perturbations of plasma parameters associated with the shocks are on the order of tens of the percent of their background values. We have repeated the simulations and the analysis for the randomized beams with the temporal incoherence using RPP and SSD corresponding to NIF parameters. For SSD we have also examined the influence of the inherent speckle motion on the ponderomotive force and the shock formation. We have established scaling laws accounting for the SSD parameters. Results of the simulations and theoretical analysis are also discussed in the context of the planned NIF experiments.

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Unsupervised Discovery of Non-Linear Plasma Physics using Differentiable Kinetic Simulations

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Plasma supports collective modes and particle-wave interactions that leads to complex behavior in inertial fusion energy applications. While plasma can sometimes be modeled as a charged fluid, a kinetic description is useful towards the study of nonlinear effects in the higher dimensional momentum-position phase-space that describes the full complexity of plasma dynamics.

By constructing kinetic solvers using a differentiable framework, we create a self-learning plasma physics loop. Differentiable programming enables this loop to perform gradient-based optimization of neural networks with an objective of minimizing/maximizing arbitrary functions of the simulation results with respect to input parameters or initial conditions. We introduce a free energy metric that maximizes the electrostatic response as well as the non-Maxwellian-ness of the electron distribution function.

We use our auto-didactic loop with the free energy metric to learn a black-box function that provides forcing function parameters that lead to new non-linear physics of electrostatic finite-length plasma wavepackets such as those seen in Stimulated Raman Scattering. If time permits, we will 1/ walk through an illustrative example of how this loop can be applied to recover well-understood physics in the linear regime 2/ further discuss the impact of the non-linear phenomenon, and 3/ discuss the implementation and the computational limitations

Measurements of anisotropic electron temperatures in magnetized gas-jet plasmas*

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Experiments at the Omega Laser Facility have utilized a magnetized gas-jet platform to infer anisotropic electron temperatures $(T_{e,\parallel} \approx 2T_{e,\perp})$ in a low-density nitrogen plasma $(n_e = 5 \times 10^{18}\ cm^{-3})$. With a 15-T field, the magnetic-field pressure is comparable to the plasma electron pressure $(\beta \approx 2)$. Thomson-scattering analysis shows the spectral density function changes relative to the axis of the magnetic field. This temperature anisotropy persists on a nanosecond time scale, well exceeding collision time scales at these conditions.

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Experimental observation of the transition from electrostatic toward electromagnetic collisionless shocks in laser driven plasmas*

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There exists a set of conditions where electrostatic collisionless shocks are unstable to streaming instabilities causing the generation and amplification of magnetic fields. Given right conditions, the streaming instabilities can produce an electromagnetic shock. In this poster, we present results from experiments accessing this regime preformed on the OMEGA laser facility. A CH supersonic plasma flow collides with a hydrogen gas jet gas puff to create a collisionless shock. Imaging 2ω Thomson scattering, D^3He backlit proton radiography, and electron spectroscopy diagnose the shock. Thomson scattering measurements show a large increase in density and temperature for the shock and prove low collisionality. Proton radiographs and associated reconstructions show a strong electrostatic potential early in time. Later in time, this potential decays away into a turbulent-like structure. Filamentation structures due to the beam-Weibel instability emerge and increase in wavelength with time. Electron spectroscopy data show the acceleration of electrons with a high energy power-law tail. PIC simulations show the formation of an electrostatic shock and the generation of magnetic fields due to instabilities. In total, these data show an electrostatic shock decaying and transitioning toward an electromagnetic shock.

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50th Annual Anomalous Absorption Conference
Sky Top, PA
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Modeling laser-driven ablative magnetothermal instability*

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The magnetothermal instability in plasmas is related to the interplay of heat flow and magnetic-field transport. The instability growth rates depend on the transport coefficients used. Recent modifications to transport coefficients in magnetized plasma have been suggested in the regime of Hall parameter χ of the order of 1 for magnetic-field diffusion, advection, and heat conduction.[1–3] A perturbation analysis is presented that studies the instability growth in laser-ablated plasmas from cylindrical wires driven with a 1-MA current.[4] The new instability growth rates are compared with the results of full hydrodynamic simulations

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

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An extended Vlasov–Fokker–Planck approach to laser absorption and pondermotive transport effects*

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It has long been recognized that intense laser fields can modify electron transport in inertial confinement fusion plasmas, especially near the critical density where a steep intensity gradient develops. A detailed kinetic description of transport in this scenario should account for ponderomotive forces, collisional absorption, and electron–electron collisions with minimal approximations. The difficulty comes from the time- and length-scale constraints imposed by the rapidly oscillating laser field, which makes naïve transport simulations infeasible. To circumvent this, we developed an extended Vlasov–Fokker–Planck approach where the distribution function is split into quasi-static (dc) and quasi-harmonic (ac) components, which obey coupled kinetic equations. The coupling terms give rise to inverse bremsstrahlung absorption, pondermotive stresses, and modifications to the electron–electron collision operator. We have implemented these new operators in the K2 Vlasov–Fokker–Planck code using an implicit scheme for stability. We present results on nonlinear inverse bremsstrahlung absorption considering both monochromatic and broadband intensity spectra. We also present results on electron heat transport and discuss how ponderomotive effects modify the heat flux for near-critical-density plasmas.

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Agenda

Friday, June 10

Experimental platforms			
Chair: Bates		Speaker	Title
8:30A	Invited	Di Stefano	Modeling of a hybrid direct/indirect-drive scheme for producing complex hydrodynamic profiles involving co-propagating shocks
9:00A	Oral	Albright	Effects of mass ablation on fusion ignition and burn propagation in layered fusion capsules
9:20A	Oral	Epstein	Quantification and assessment of radiation-trapping efficiency in inertial confinement fusion implosion experiments based on characteristic quantities of simple models
9:40A	Oral	LeFevre	Experiments to study strongly coupled radiative shocks on the OMEGA laser
10:00A	Break		
Laser-plasma instabilities			
Chair: Milder			
10:30A	Oral	Simpson	High-energy two-color terahertz generation
10:50A	Oral	Weaver	Broad Bandwidth Laser Development for LPI mitigation at NRL
11:10A	Oral	Ludwig	Comparison of Optical Smoothing Techniques for Mitigation of Filamentation
11:30A	Oral	Cao	Predicting hot electron generation in inertial confinement fusion with particle-in-cell simulations
11:50P	Oral	Stark	Nonlinear Models for Coupling the Effects of Stimulated Raman Scattering to Inertial Confinement Fusion Design Codes
12:30P	Lunch		

Modeling of a hybrid direct/indirect-drive scheme for producing complex hydrodynamic profiles involving co-propagating shocks*

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The interaction of multiple, co-propagating shocks at an unstable material interface is an important process in many high-energy-density (HED) systems. It has been theorized to produce different hydrodynamic outcomes than for the case of counter-propagating shocks [1]. These interactions remain understudied due to the significant experimental challenge of producing multiple, co-propagating shocks in a planar system at a diagnosable scale. We present experimental and computational results showing progress in studying the effects of co-propagating planar shocks and discuss how we can apply these shocks to the study of interfacial instability.

This platform (initially presented in [2]) uses a halfraum-driven target package with shocks launched by a hybrid, sequential direct- and indirect-drive scheme. It overcomes the difficulty of producing two shocks in the same location, where the second shock is necessarily under dynamically evolving plasma conditions and needs to be faster than the first one. This allows for each shock to be independently controlled, permitting significant flexibility in the strength and timing of these shocks. The indirect-drive scheme is tailored for the National Ignition Facility (NIF), with complementary, parallel experiments performed on the OMEGA Laser Facility. The primary modeling effort is performed using the Los Alamos Eulerian, multi-physics, radiation-hydrodynamics code xRAGE [3], which employs the LLE Mazinisin laser package [4] and includes effects of Cross Beam Energy Transfer (CBET) in this unique direct / in-direct drive scenario. Cross-code comparisons using HYDRA [5] are shown as well. We will show experimental results demonstrating and characterizing a successively shocked interface and compare with our current predictive capability.

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Effects of mass ablation on fusion ignition and burn propagation in layered fusion capsules*

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Fusion ignition in layered capsules involves a complex interplay between a dynamically forming hot spot and the dense surrounding fuel. Using analytic theory[1], a traveling wave solution to the nonlinear isobaric heat transport equation can be obtained, from which the mass ablation rate of dense DT fuel into the hot spot may be estimated. This ablation rate can be as much as 3-4× higher than previous theoretical estimates, which generally underpredict the mass ablation rate. These ablative inflows lead to an influx of enthalpy into the hot spot that plays a critical role in the burn dynamics, ultimately controlling the hot spot temperature, the ignition threshold, and the subsequent burn propagation. The net influence of mass ablation on the ignition threshold is characterized by a dimensionless quantity that encapsules the conditions at the edge of the hot spot relative to the central core. These theoretical predictions have been confirmed using radiation hydrodynamic simulations for a series of HYBRID-E capsules near ignition and they may provide an explanation for the variable performance of recent ignition and near-ignition shots observed on the NIF.

*This work was performed under the auspices of the U.S. Department of Energy by Triad National Security, LLC, operator of the Los Alamos National Laboratory under Contract No. 89233218CNA000001.

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[1] W. Daughton, B. J. Albright, S. M. Finnegan, B. M. Haines, J. L. Kline, J. P. Sauppe, and J. M. Smidt , "*Influence of mass ablation on ignition and burn propagation in layered fusion capsules,*" (submitted)

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Quantification and assessment of radiation-trapping efficiency in inertial confinement fusion implosion experiments based on characteristic quantities of simple models*

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Achieving high-temperature "volume-burn" ignition conditions in inertial confinement fusion implosions requires an opaque inner pusher layer to contain the DT fuel mass and minimize the escape of thermal energy from the fuel in the run-up to ignition conditions. Volume burn involves the entire fuel mass igniting at once, as opposed to conventional "hot-spot" ignition by a propagating burn wave. Single-shell "pushered" implosions utilize an opaque high-*Z*, inner-shell lining to "trap" the radiation that would otherwise escape the core, cooling the fuel below the temperature required for ignition. We employ existing analytic physical models and numerical radiation-hydrodynamic simulations and utilize enhanced radiation-visualization tools to arrive at a meaningful measure of the effectiveness of radiation trapping. By approximating the escaping radiation flux with the Marshak wave model, useful characteristic trapping quantities are identified and expressed in terms of core and shell parameters. This model is extended to allow for the converging geometry and simple hydrodynamic motion of the stagnating shell. The radiative flux that escapes the fuel is a much more important consideration than the radiation energy that is literally trapped in the fuel. Opaque shell linings are strong absorbers, not mirrors, and they reduce fuel cooling only to the extent that they retard the energy flux through the shell.

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Experiments to study strongly coupled, radiative shocks on the Omega laser*

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Strongly coupled plasmas occur in compact objects such as white dwarf and neutron stars. Radiative shocks can be present in these objects either in accretion columns or violent interactions on their surfaces. The work on radiative shocks typically assumes the plasma is weakly coupled, which is not necessarily true especially for mid-Z elements. It is therefore necessary to investigate the overlap of these two physics regimes and explore the effects of strongly coupled plasmas on radiation hydrodynamics.

This work describes experiments on the Omega laser facility to implode capsules with a metal layer on the interior surface to produce a strongly coupled, radiative shock over a range of materials to exploit the Z^2 dependence of the ion-ion coupling parameter. Modeling with the HELIOS-CR code suggests that there is a radiative rebounding shock after the implosion stagnates through the strongly coupled metal. Varying the metal from low to mid-Z allows for a range of coupling parameters from about 0.3 to 10. This work is in preparation for upcoming NLUF experiments, and it presents some preliminary results.

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High-energy two-color terahertz generation*

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A laser pulse composed of a fundamental and properly phased second harmonic exhibits an asymmetric electric field that can drive a time-dependent current of photoionized electrons. The current produces a near-single-cycle burst of terahertz (THz) radiation. Experiments using ~1-TW ultrashort laser pulses observe optimal THz energies (~10-μJ) when the "two-color" pulse undergoes filamentary propagation in low pressure gas.[1] Here we use simulations to investigate the optimal conditions for two-color THz generation driven by >100-TW ultrashort laser pulses. Simple scalings indicate that the number of photoionized electrons is independent of laser power and pressure. As a result, use of a low-pressure, small nonlinear refractive index, high-ionization potential gas such as helium can mitigate multiple filamentation of the high-power pulse, while strengthening the field experienced by electrons at the instant of ionization, thereby increasing the current and THz energy. A high-energy (~1-mJ), THz source would enable access to a novel physics regime in which bound electron nonlinear optics and relativistic plasma physics coexist.

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

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Broad Bandwidth Laser Development for LPI mitigation at NRL*

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Research at the Naval Research Laboratory pursues advanced sources that can mitigate laser-plasma instabilities (LPI) in applications such as inertial confinement fusion. This presentation will discuss the two main components of the current program: stimulated Rotational Raman scattering (SRRS) and Argon-Fluorine (ArF) excimer lasers. Stimulated rotational Raman scattering (SRRS) has been demonstrated on the Nike laser facility [Weaver, Applied Optics, 2017] as a path with potential application at existing laser facilities. Through a combination of high intensity propagation and control of the laser spectrum in the low-energy stages of the laser, the output spectrum of Nike has been broadened from an intrinsic 1 THz bandwidth to ~5 THz. This amount of bandwidth has been shown to be effective for mitigation of slower growing instabilities, such as cross-beam energy transport (CBET) [Bates, High Energy Density Physics, 2020]. Target experiments using this capability are being planned. The development of Argon-Fluorine lasers [Wolford, High Energy Density Physics, 2020] is a more recent addition to the NRL program. This advanced system looks particularly useful for LPI mitigation due its short wavelength (193 nm) and potential for bandwidths approaching ~10 THz. The development effort at NRL's Electra laser facility has reached record output energies for an ArF system and has begun to evaluate the characteristics of the output spectrum for different modes of operation.

* Work supported by DoE/NNSA.

Comparison of Optical Smoothing Techniques for Mitigation of Filamentation*

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Intense laser hotspots/speckles are a concern on high power laser facilities due to their role in seeding unwanted instabilities such as SBS (Stimulated Brillouin Scattering) or laser filamentation. Optical smoothing techniques such as SSD[1,2] (Smoothing by Spectral Dispersion) are used to better homogenize the laser focal spot intensity pattern on the time scale of the instabilities. While SSD uses sinusoidal phase modulation, Stiletto[3] is a new technique that allows for arbitrary control of a laser's frequency and amplitude of as a function of time. Here we report on a project that examines the use of Stiletto for optical smoothing in comparison to SSD. An overview of the simulation technique will be presented with updates on simulations of filamentation mitigation with Stiletto.

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Predicting hot electron generation in inertial confinement fusion with particle-in-cell simulations*

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A series of 2D Particle-In-Cell simulations was carried out to study hot-electron generation in direct-drive inertial confinement fusion on OMEGA. Scaling laws were obtained for hot electron fraction and temperature as functions of laser/plasma conditions in the quarter-critical region. Using these scalings and conditions from hydro simulations, hot electrons in an implosion can be predicted from beginning to end. After accounting for realistic laser smoothing techniques, speckle statistics and inaccuracies in hydro simulations, the predicted hot electrons for a collection of OMEGA warm target implosions agreed with the experimental data within experimental error bars. These scalings can readily be implemented into ICF design codes.

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Nonlinear Models for Coupling the Effects of Stimulated Raman Scattering to Inertial Confinement Fusion Design Codes*

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Laser plasma instabilities reduce driver-target coupling and fundamentally limit fusion performance in inertial confinement fusion (ICF). Being able to predict and model LPI effects in design codes is important for the success of ICF. We present VPIC particle-in-cell simulations of multi-speckled laser beams undergoing stimulated Raman scattering (SRS) at various densities and intensities relevant to indirectly-driven ICF systems. Based on the wavenumber of the SRS daughter electron plasma wave, regions with underpinning SRS saturation physics are identified: an electron-trapping dominated region with intermediate $k\lambda_D$ values, a strong damping region at larger $k\lambda_D$ values, and a region with the presence of the Langmuir decay instability at lower $k\lambda_D$ values. We developed a nonlinear SRS reflectivity model that features the base scaling $(k\lambda_D)^{-4}$ and its modifications. Electron trapping deforms the underlying electron distribution functions, and we have developed a new δf-Gaussian-mixture algorithm for an accurate characterization of the trapped particle population. With this SRS hot-electron description, we propose a nonlinear energy deposition model and a hot-electron source model, based on the Manley-Rowe relations, which is suitable for including SRS effects as a sub-grid module in a high-fidelity ICF design code.

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