2015 Anomalous Absorption Conference

Program

June 14-19, 2015
Ventura Beach, CA

	Monday, June 15th					
7:00 - 8:00	Breakfast					Miguel B
	Chair: Thomas Kwan					Miguel A
7:55-8:00	Welcome	Frank	Tsung	UCLA		
8:00-8:30	Beryllium implosion experiments on the National Ignition Facility	Austin	Yi	LANL	austinyi@lanl.gov	
8:30-8:50	High Foot Implosions in Large Cylindrical Hohlraums	Denise	Hinkel	LLNL	hinkel1@llnl.gov	
8:50-9:10	Investigation of beam non-uniformity after cross-beam energy transfer on the National Ignition Facility	Louisa	Pickworth	LLNL	pickworth1@llnl.gov	
9:10-9:30	Inline Modeling of Cross-Beam Energy Transfer and Stimulated Raman Scattering in Radiation- Hydrodynamics Codes	David	Strozzi	LLNL	strozzi2@llnl.gov	
9:30-9:50	Collective stimulated Brillouin scattering in multiple beams interaction	Sylvie	Depierreux	CEA,DAM,DIF	sylvie.depierreux@polytechnique.edu	
9:50-10:10	Multibeam Seeded Brillouin Sidescatter in Inertial Confinement Fusion Experiments	David	Turnbull	LLNL	turnbull2@llnl.gov	
10:10-10:30	Break					
	Chair: Denise Hinkel					
10:30-11:00	Multi-beam stimulated Raman scattering in ICF conditions	Pierre	Michel	LLNL	michel7@llnl.gov	
11:00-11:20	Diagnosing Cross-Beam Energy Transfer Using Beamlets of Unabsorbed Light from Direct-Drive Implosions	Dana	Edgell	University of Rochester	dedg@lle.rochester.edu	
11:20-11:40	Quantifying the Growth of Cross-Beam Energy Transfer in Polar-Direct-Drive Implosions	Amanda	Davis	LLE	adavi@lle.rochester.edu	
11:40-12:00	The Effects of Beam Incoherence and Colors on Cross-Beam Energy Transfer	Andre	Maximov	LLE	amax@lle.rochester.edu	
12:00-12:20	Effects of Cross-Beam Energy Transfer on Scattered-Light Spectra from OMEGA and National Ignition Facility Implosions	Wolf	Seka	LLE	seka@lle.rochester.edu	
	Chair: Peter Amendt					Miguel A
7:00 - 8:00	Exploring the Scaling of Missing Energy and Backscatter with Hohlraum Gas Fill, Case/Capsule Ratio, and Pulse Length*	Ogden	Jones	LLNL	oggie@llnl.gov	

Monday, June 15th

Buena Ventura Room

1	Reduced convergence implosions using liquid layer wetted foam capsules on the National Ignition Facility	Austin	Yi	LANL	austinyi@lanl.gov
2	Hot Spot Dynamics in Shock Ignition	Claudio	Bellei	CELIA	bellei@celia-bordeaux1.fr
3	Wave Bowing and Modulational Instability of Ion Acoustic Waves in 2D Vlasov simulations	Richard	Berger	LLNL	berger5@llnl.gov
4	Kinetic Effects in Inertial Confinement Fusion	Grigory	Kagan	LANL	kagan@lanl.gov
5	2D Simulations of 3D-Printed Ignition Double-Shell Targets	Jose	Milovich	Lawrence Livermore National Laboratory	milovich1@llnl.gov
6	Laser-generated magnetic field characterization on the nanosecond timescale	Clament	Goyon	LLNL	goyon1@llnl.gov
7	CBET Experiments at the Nike laser	James	Weaver	NRL	james.weaver@nrl.navy.mil
8	Effects of magnetization on fusion product trapping and secondary neutron spectra	Paul	Schmit	Sandia National Laboratories	pfschmi@sandia.gov
9	Multi-dimensional dynamics of stimulated Brillouin scattering and seeded two-ion-wave decay in laser speckle geometry	Brian	Albright	LANL	balbright@lanl.gov
10	Laser Plasma Interactions with Temporal Bandwidths	Frank	Tsung	UCLA	tsung@physics.ucla.edu
11	Role of shock-timing in two-shock platform	Natalia	Krasheninnikova	LANL	nkrash@lanl.gov

Tuesday, June 16th

7:00 - 8:00	Breakfast					Miguel B
	Chair: Dustin Froula					Miguel A
8:00-8:30	Zakharov Modeling of Thomson-Scattering Measurements of Multibeam Two-Plasmon Decay	Russell	Follett	LLE	rfollett@lle.rochester.edu	
8:30-8:50	Planar Two-Plasmon–Decay Experiments at Polar-Direct-Drive Ignition-Relevant Scale Lengths at the National Ignition Facility	Michael	Rosenberg	LLE	mros@lle.rochester.edu	
8:50-9:10	Absolute Two-Plasmon Decay and Stimulated Raman Scattering in Direct-Drive Irradiation Geometries	Robert	Short	University of Rochester	rsho@lle.rochester.edu	
9:10-9:30	A Three-Dimensional Model for Hot-Electron Generation in Direct-Drive Implosions	Jason	Myatt	LLE	jmya@lle.rochester.edu	
9:30-9:50	Two-plasmon decay instabilities in a plasma with ion density fluctuations	Jun	Li	University of Rochester	cren@lle.rochester.edu	
9:50-10:10	Dynamic-Bandwidth-Reduction Experiments on the OMEGA Laser	Dustin	Froula	LLE	dfroula@lle.rochester.edu	
10:10-10:30	Break					
	Chair: David Strozzi					
10:30-11:00	Channeling Kilojoule Laser Pulses Through Long-Scale-Length Plasmas	Steven	Ivancic	LLE	siva@lle.rochester.edu	
11:00-11:20	Electron shock ignition of thermonuclear fuel	Ricardo	Betti	LLE	betti@lle.rochester.edu	
11:20-11:40	Improved fast heating coupling efficiency to laser-compressed deuterated plastic shells via visualization of fast electron transport	Christopher	McGuffey	UCSD	cmcguffey@ucsd.edu	
11:40-12:00	Fast-Electron Temperature Measurements in Laser Irradiation at 10^14 to 10^15 W/cm^2	Andre	Solodov	LLE	asol@lle.rochester.edu	
12:00-12:20	Heat-Flux Measurements from Thomson-Scattering Spectra	Robert	Henchen	LLE	rhen@lle.rochester.edu	
	Chair: Ben Winjum					Miguel A
7:00 - 8:00	High energy density physics research at SLAC	Frederico	Fiuza	SLAC	fiuza@slac.stanford.edu	

Tuesday, June 16th

Buena Ventura Room

1	SECHEL: a CBET post-processor for hydro codes Recent results and related studies	Michel	Casanova	CEA	michel.casanova@cea.fr
2	Multi-scale Fokker-Planck modeling of α-particle transport in igniting ICF capsules	Olivier	Larroche	CEA	olivier.larroche@cea.fr
3	High-foot NIF beryllium targets with 6.72-mm cylindrical hohlraums with low gas fills	Andrei	Simakov	LANL	simakov@lanl.gov
4	Mounting stalk effects on the burn in separated- reactant capsules*	Mark	Schmitt	LANL	mjs@lanl.gov
5	Application of Imposed Magnetic Fields to Ignition and Thermonuclear Burn on the National Ignition Facility	David	Strozzi	LLNL	strozzi2@llnl.gov
6	Ion acoustic wave decay to two daughter waves using a 2D+2V Vlasov code†	Thomas	Chapman	LLNL	chapman29@llnl.gov
7	Vlasov Simulation of the Effects of Pitch Angle Collisions in Electron Plasma Waves	Jeffrey	Banks	RPI	banksj3@rpi.edu
8	Three-Dimensional Full-Beam Simulation of Ultrashort Laser Pulse Amplification by Brillouin Backscattering	Kathleen	Weichman	University of Texas	berger5@llnl.gov
9	Proton acceleration in the interaction of high power laser and cryogenic hydrogen targets	Rohini	Mishra	SLAC	rohinimishra2003@gmail.com
10	Vlasov Fokker Planck modeling of High Energy Density Plasmas	Adam	Tableman	UCLA	tableman@physics.ucla.edu

	Wednesday, June 17th					
7:00 - 8:00	Breakfast					Miguel B
	Chair: Suxing Hu					Miguel A
8:00-8:30	Ion-kinetic effects in ICF	Olivier	Larroche	CEA	olivier.larroche@cea.fr	
8:30-8:50	Off-axis stagnation of a high-Z hohlraum wall onto a capsule ablator: hydrodynamics vs. collisional-PIC modeling	Laurent	Divol	LLNL	divol1@llnl.gov	
8:50-9:10	An Ideal Hohlraum Platform Using Double-Shell Ignition Targets	Peter	Amendt	LLNL	amendt1@llnl.gov	
9:10-9:30	Simulating the growth of small perturbations in laser-driven ICF planar targets using the FAST3D code	Jason	Bates	NRL	jason.bates@nrl.navy.gov	
9:30-9:50	Effects of Long- and Intermediate-Wavelength Asymmetries on Hot-Spot Energetics	Arijit	Bose	LLE	abos@lle.rochester.edu	
9:50-10:10	Sensitivity of hot spot properties to the cold DT fuel adiabat and interfacial instabilities	Baolian	Cheng	LANL	bcheng@lanl.gov	
10:10-10:30	Break					
	Chair: Scott Wilks					
10:30-11:00	First principles based EOS model of carbon for HEDP and ICF applications	Lorin	Benedict	LLNL	benedict5@llnl.gov	
11:00-11:20	Extended Equation of State of Polystyrene (CH) Based on First-Principles Calculations	Suxing	Hu	LLE	shu@lle.rochester.edu	
11:20-11:40	The Release Behavior of Diamond Shocked to 15 Mbar	Michel	Gregor	LLE	mgreg@lle.rochester.edu	
11:40-12:00	Three-dimensional Single-mode Nonlinear Ablative Rayleigh-Taylor Instability	Rui	Yan	LLE	ryan@lle.rochester.edu	
12:00-12:20	PHYSICS AND DESIGNS OF IGNTION CAPSULES USING HIGH- DENSITY CARBON (HDC) ABLATORS: ROBUST DESIGNS, STABILTY, PICKETED PULSES, AND SHOCK MERGES	Darwin	Ho	LLNL	ho1@llnl.gov	
	Chair: Matthias Geissel					Miguel A
7:00 - 8:00	Adventures in ICF with magnetic fields	Adam	Sefkow	Sandia National Laboratories	absefko@sandia.gov	
12:30	Business Meeting					Miguel A

Wednesday, June 17th

Buena Ventura Room

1	Ion-kinetic simulations of D3He gas-filled ICF target implosions with moderate to large Knudsen number	Olivier	Larroche	CEA	olivier.larroche@cea.fr
2	Saturation of Cross-Beam Energy Transfer for Multi-Speckled Laser Beams	Lin	Yin	LANL	lyin@lanl.gov
3	iFP: An Optimal, Fully Implicit, Fully Conservative, 1D2V Vlasov-Rosenbluth-Fokker-Planck Code for ICF Simulation	William	Taitano	LANL	taitano@lanl.gov
4	SYMMETRY OF BERYLLIUM CAPSULE IMPLOSION AT THE NATIONAL IGNITION FACILITY	George	Kyrala	LANL	gak@lanl.gov
5	Controlling Laser-Driven Hohlraums- Clues from Experiments with Earlier Lasers	William	Kruer	LLNL	williamkruer@gmail.com
6	HOT SPOT DYNAMICS AND IGNITION BOUNDARIES FOR HIGH- DENSITY CARBON (HDC) CAPSULES	Darwin	Ho	LLNL	ho1@llnl.gov
7	Semi-analytic Knudsen-layer reactivity reduction model for spheroidal cavities	Paul	Schmit	Sandia National Laboratories	pfschmi@sandia.gov
8	Recent progress on understanding LWFA in the nonlinear self-guided blowout regime	Asher	Davidson	UCLA	physicksislife@gmail.com
9	Laser Absorption at Over-Critical Surfaces	Josh	May	UCLA	joshmay@ucla.edu
10	Recent results on laser-plasma interactions in shock ignition	Chuang	Ren	University of Rochester	cren2@ur.rochester.edu

	Thursday, June 18th				
7:00 - 8:00	Breakfast				Miguel B
	Chair: Christopher McGuffey				Miguel A
8:00-8:30	Efficient ion beams with narrow energy spread from laser-driven relativistic plasma accelerators using giant self-generated plasma fields	Sasi	Palaniyappan	LANL	sasi@lanl.gov
8:30-8:50	Numerical Cerenkov instability in LWFA Lorentz boosted frame simulation and relativistic collisionless shock simulation	Peicheng	Yu	UCLA	tpc.1983@gmail.com
8:50-9:10	Towards a Robust Plasma Wave Amplifier	Peter	Norreys	Imperial College/RAL	peter.norreys@physics.ox.ac.uk
9:10-9:30	Studies on the Saturation Limit of Stimulated Raman Backscattering	Jun	Ren	DESU	jren@desu.edu
9:30-9:50	Effects of Spontaneous Magnetic Fields on the Propagation of Supersonic Plasma Jets	Chikang	Li	MIT	ckli@mit.edu
9:50-10:10	Electron Dynamics in High Energy Density Magnetized Plasmas	Archis	Joglekar	University of Michigan	archisj@umich.edu
10:10-10:30	Break				
	Chair: Chikang Li				
10:30-11:00	Ion Thermal Decoupling and Species Separation in Shock-Driven Implosions	Hans	Rinderknecht	MIT	hgr@mit.edu
11:00-11:20	Shock-Induced Mix Across an Ideal Interface	Claudio	Bellei	CELIA	bellei@celia-bordeaux1.fr
11:20-11:40	Insights into Proton Radiographic Images of Hohlraums	Scott	Wilks	LLNL	wilks1@llnl.gov
11:40-12:00	Electron Temperature Measurement of NIF Hohlraum Plasmas Using Dot Spectroscopy	Maria	Barrios	LLNL	barriosgarci1@llnl.gov
12:00-12:20	Measurements of the Conduction-Zone Length and Mass Ablation Rate in Cryogenic Direct-Drive Implosions on OMEGA to Restrict Thermal-Transport Models	Tomline	Michel	LLE	tmic@lle.rochester.edu

Friday, June 19th

7:00 - 8:00	Breakfast				Miguel B
	Chair: Peter Norreys				Miguel A
8:00-8:30	Development of Predictive Models of Absorption of High Power Laser Light by Optically-Thick Materials	Matthew	Levy	U. Oxford	matthew.levy@physics.ox.ac.uk
8:30-8:50	High-Z coatings for Hybrid Laser Indirect-Direct Drive	Max	Karasik	NRL	karasik@nrl.navy.mil
8:50-9:10	LEH Transmission and Early Fuel Heating for MagLIF with Z-Beamlet	Matthias	Geissel	Sandia National Laboratories	mgeisse@sandia.gov
9:10-9:30	The relationship between gas fill density and hohlraum drive performance at the National Ignition Facility	Gareth	Hall	LLNL	hall98@llnl.gov
9:30-9:50	Break				
	Chair: Frank Tsung				
9:50-10:20	Results from trailing-bunch acceleration in recent Plasma Wakefield Acceleration experiments at the FACET Facility at SLAC National Accelerator Laboratory	Chris	Clayton	UCLA	cclayton@ucla.edu
10:20-10:40	pF3D Simulations of Stimulated Brillouin Scattering in Rugby Hohlraums on NIF	Steven	Langer	LLNL	langer1@llnl.gov
10:40-11:00	Stimulated Raman Backscatter Trends from Gas Filled Hohlraum Experiments on the NIF	Joe	Ralph	LLNL	ralph5@llnl.gov
11:00-11:20	Modifying the Kinetic Behavior of Stimulated Raman Scattering with External Magnetic Fields	Benjamin	Winjum	UCLA	bwinjum@ucla.edu
	See you next year!				

Beryllium implosion experiments on the National Ignition Facility*

S. A. Yi, A. N. Simakov, D. C. Wilson, J. L. Kline, R. E. Olson, G. A. Kyrala, T. S. Perry, and S. H. Batha
Los Alamos National Laboratory

E. L. Dewald, J. E. Ralph, D. A. Callahan, D. E. Hinkel, O. A. Hurricane, D. J. Strozzi, D. S. Clark, B. A. Hammel, J. L. Milovich, R. Tommasini, M. B. Schneider, A. G. MacPhee
Lawrence Livermore National Laboratory

Beryllium is an attractive capsule material that ablates more efficiently[1] and minimizes capsule hydro-instability growth in ICF implosions[2]. Due to a higher ablation rate beryllium targets are able to reach higher velocities for a given drive, while also increasing ablative stabilization of Rayleigh-Taylor instabilities at the ablation front. Alternatively, beryllium targets can utilize more massive fuel payloads in order to achieve the same fuel areal density with decreased convergence. However, this enhanced ablation rate also leads to increased hohlraum plasma density, thereby possibly inhibiting laser propagation, increasing the SRS and SBS backscatter, and exacerbating anomalous drive degradation. Thus, successful beryllium implosions must exploit its advantageous ablation properties while keeping the hohlraum plasma conditions in check.

A national campaign is currently underway to evaluate the performance of beryllium targets in integrated indirect-drive experiments at NIF. A series of tuning shots have been performed, including keyhole, symcap, and 1D and 2D convergent ablator experiments. The results show that the coupling of the laser energy is slightly improved in beryllium targets as compared with high foot CH, provided a suitable laser pulse shape is utilized to control the hohlraum plasma conditions. SRS and SBS backscatter in beryllium targets have been measured, and are similar to those in high foot CH experiments. Preliminarily, the experimental data suggests that the laser pulse shape may have a stronger effect in determining late-time hohlraum plasma conditions than the blow-off rate of the capsule ablator material. Initial shape data from x-ray self-emission and backlighter images suggests that the implosion symmetry can be improved by increasing the effective inner cone laser power. The data gathered so far is being used to optimize the first beryllium experiment with a DT fuel layer for shock timing, implosion symmetry, and hohlraum performance.

*This work was performed at LANL, operated by LANS, LLC for the U.S. DoE under Contract No. DE-AC52-06NA25396; and at LLNL, operated by LLNS, LLC for the U.S. DoE under Contract No. DE-AC52-07NA27344.

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[1] R. E. Olson et al., "*X-ray ablation rates in inertial confinement fusion capsule materials*", Phys. Plasmas **18**, 032707 (2011).

[2] S. A. Yi et al., "*Hydrodynamic instabilities in beryllium targets for the National Ignition Facility*", Phys. Plasmas **21**, 092701 (2014).

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High Foot Implosions in Large Cylindrical Hohlraums*

D. E. Hinkel, L. F. Berzak Hopkins, O S. Jones, D. A. Callahan, and O. A. Hurricane
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Recent High Foot implosions at the National Ignition Facility (NIF), where the laser power is high early in time, i.e., during the "foot", have resulted in record neutron yields [1]. To obtain near-spherical, low-mode implosion symmetry, these targets have relied on cross-beam energy transfer (CBET), where outer beam power is transferred to the inner beams [2]. CBET has a temporal dependence, as large amounts of transfer occur early in the laser pulse, when the electron temperature is low, and at peak power, when the laser intensity is at its highest. Furthermore, there is also spatial non-uniformity across laser spots after transfer.

To obtain good inner beam propagation without the use of CBET, we propose a High Foot implosion in a hohlraum that is 1.17 times larger than typically used. This hohlraum is filled with an intermediate gas fill density (0.6 mg/cc) rather than with the nominal 1.6 mg/cc gas fill . This larger hohlraum with intermediate fill density has performed well for the shorter pulse lengths driving implosions with high density carbon (HDC) ablators [3]. In these experiments, there is growing evidence of correlation between predictability and low levels of laser backscatter, hot electrons, and CBET. The challenge here is to maintain the predictability shown by simulation at the longer pulse lengths necessary for plastic ablators.

The first test of a High Foot implosion in this larger hohlraum will be a shock timing tuning shot in late May. This shot will provide not only shock timing information, but also a first look at drive deficit and laser backscatter on the rise to and early in peak power. Analysis and results of both the ignition design and the shock timing tuning shot will be presented.

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

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[1] Hurricane *et al.*, *Nature* **506**, 343-348 (2014).

[2] P. Michel *et al.*, Phys. Plasmas **17** , 056305 (2010).

[3] P. A. Amendt, D. D. Ho, O. S. Jones, *et al.*, submitted to Phys. Rev. E, 2015.

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Investigation of beam non-uniformity after cross-beam energy transfer on the National Ignition Facility

L.A. Pickworth, M.B. Schneider, D.E. Hinkel, M.D. Rosen, D.A. Callahan, P.A. Michel,
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Control of hotspot symmetry in an ignition capsule imploded by the x-ray drive in a high gas-filled cylindrical hohlraum at the National Ignition Facility (NIF) currently requires cross-beam energy transfer (CBET) from the outer beams to the inner beams [1]. CBET occurs in the central region of the laser entrance hole (LEH) where the laser beams overlap. The overlapping laser beams create a Bragg-like density grating in the plasma that scatters laser power from one beam cone to another. The amount of transfer is controlled by the wavelength difference, $\Delta\lambda$, between the laser cones and is proportional to laser intensity, is inversely proportional to the electron temperature, T_e and depends upon the plasma flow velocity in the LEH. The rate of CBET is highest during peak laser power, when the intensity is maximum, and during the picket where T_e in the LEH is low.

Linear gain models applied to individual rays indicate that CBET is not uniform across the beam profile, producing a non-uniform spatial distribution on the beams that varies in time. This changing spatial distribution could introduce asymmetries in the x-ray drive applied to the ignition capsule and should be quantified.

We are investigating the effects of CBET in the early time of the laser pulse (the picket) using the Quartraum experimental platform. This platform uses an LEH-only target designed to isolate the effect of CBET on the spatial-intensity distribution of the inner beams by minimizing the effect of absorption and backscatter. Using a laser pulse that extends the picket drive, a time resolved image of two inner beams is captured on a high Z witness plate. Experimental results showing how the beam's x-ray foot print on the witness plate changes as a function of $\Delta\lambda$ will be shown and compared to models.

[1] P. Michel et al., Phys. Plasmas 16, 042702 (2009)

* Prepared by LLNL under Contract DE-AC52-07NA27344. LLNL-ABS- 669855

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Inline Modeling of Cross-Beam Energy Transfer and Stimulated Raman Scattering in Radiation-Hydrodynamics Codes*

D. J. Strozzi, S. M. Sepke, G. D. Kerbel, D. S. Bailey, P. Michel,
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Models for cross-beam energy transfer (CBET) and stimulated Raman scattering (SRS) are being implemented in the rad-hydro codes HYDRA and LASNEX. Both processes are important in NIF ignition hohlraum experiments with high hohlraum fill-gas density, e.g. so-called "low-foot" and "high-foot" designs. The inline CBET model gives results that are close to those of the older, offline (post-processing) method, when enough numerical rays are used to adequately resolve beam intensity on the spatial mesh. The CBET model includes momentum deposition and ion heating due to driven ion waves[1]. This results in a higher ion temperature in the laser entrance hole (LEH), but small changes to the calculated transfer. The inline SRS model includes pump laser depletion, hot electron production by driven Langmuir waves, and inverse-bremsstrahlung absorption of scattered light. The resulting LEH electron temperature is significantly higher. The inner-beam intensity reaching the hohlraum wall is reduced with the inline SRS treatment as opposed to removing the escaping SRS light from the pump laser. This impairment is in addition to any CBET reduction due to the hotter LEH electrons caused by the inline SRS model.

* Work performed under the auspices of the US DoE by LLNL under Contract DE-AC52-07NA27344.

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[1] P. Michel et al., Phys. Rev. Lett. 109, 195004 (2012)

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Collective stimulated Brillouin scattering in multiple beams interaction

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P.-E. Masson-Laborde[1], C. Baccou[3], P. Fremerye[1], F. Philippe[1], P. Seytor[1],
D. Teychenné[1], W. Seka[4], J. Katz[4], R. Bahr[4]

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[3]LULI, UMR 7605 CNRS-Ecole Polytechnique-CEA-Université Paris VI, 91128 Palaiseau cedex, France
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Megajoule scale inertial confinement fusion experiments imply the crossing of ~ 100 laser beams of moderate intensity at the laser entrance hole of the *Holhraum* resulting in a superimposed intensity ~10^{16} W/cm². The laser beams overlap can be used to redistribute the energy between the various cones of beams before they reach the target, thus ultimately providing a mean to control the symmetry of the irradiation of the capsule. In the case of such a very large number of laser beams distributed in a highly symmetric configuration, the interaction of multiple beams with the plasma may be further complicated by a new type of instability. The latter collectively couples all the incident laser waves located in a cone to the daughter wave growing along the cone symmetry axis[1].

Such a collective interaction has been studied in experiments carried out on the 351 nm Omega laser facility at the University of Rochester. These experiments used a subset of 40 over the 60 beams available on the facility to irradiate gas-filled rugby shaped *Hohlraums* in an indirect-drive configuration with two incident laser beam cones representative of the megajoule facilities. Complementary diagnostics of Thomson scattering and scattered light measurements were exploited to study the collective ion acoustic wave instabilities driven by 4 to 10 beams.

The 10-beam instability is shown to give rise to large amount of scattered light losses. The growth and saturation of this instability are very well explained by the expected linear gain and by pump depletion. The efficient control of this collective instability by the temporal smoothing of the interacting beams and by the electronic density of the crossing beams domain is demonstrated in these experiments.

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[1] DuBois, D.F., Bezzerides, B. & Rose, H. A. Collective parametric instabilities of many overlapping laser beams with finite bandwidth. *Phys. Fluids B* **4**, 241-251 (1992).

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Multibeam Seeded Brillouin Sidescatter in Inertial Confinement Fusion Experiments*

David Turnbull, P. Michel, J. E. Ralph, L. Divol, J. S. Ross, L. F. Berzak Hopkins, A. L. Kritcher, D. E. Hinkel, and J. D. Moody
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We present the first observations of multibeam weakly seeded Brillouin sidescatter in indirect-drive inertial confinement fusion (ICF) experiments[1]. Two seeding mechanisms have been identified and quantified: specular reflections (“glint”) from opposite hemisphere beams, and Brillouin backscatter from neighboring beams with a different angle of incidence. Seeded sidescatter can dominate the overall coupling losses, so understanding this process is crucial for proper accounting of energy deposition and drive symmetry. Glint-seeded scattered light could also be used to probe hydrodynamic conditions inside ICF targets.

* 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] D. Turnbull *et al*., Phys. Rev. Lett. **114**, 125001 (2015).

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Multi-beam stimulated Raman scattering in ICF conditions

P. Michel, L. Divol, E.L. Dewald, J.L. Milovich, M. Hohenberger, O.S. Jones, L. Berzak Hopkins, R.L. Berger, W.L. Kruer and J.D. Moody
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Stimulated Raman scattering (SRS) from multiple laser beams sharing a common daughter wave is investigated for inertial confinement fusion (ICF) conditions in inhomogeneous plasmas. It is found that the shared-electron plasma wave (EPW) process, where the lasers collectively drive the same EPW, can lead to an absolute instability at densities below quarter-critical. This occurs when the beams, arranged in a cone geometry (as is typical of large-scale laser facilities), collectively drive an EPW along the cone axis near a "matching" electron density $n_{em}(\theta) = \cos^4(\theta)n_c/4$, where θ is the beams' incident half-cone angle and n_c the critical density. The resulting absolute intensity threshold can be much lower than the typical overlapped intensities found in ICF experiments in the beams overlap regions. It is also orders of magnitude lower than the intensities required to achieve significant growth in the convective regime, when $n_e<n_{em}(\theta)$. This instability can lead to coupling losses that ICF facilities are typically not setup to measure, as opposed to direct backscatter, and can also generate energetic electrons along the cone axis – typically towards the ICF target core. Recent observations of hot electrons in NIF experiments at densities well below quarter-critical, when TPD is not expected to occur, are shown to be consistent with the collective SRS instability.

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Diagnosing Cross-Beam Energy Transfer Using Beamlets of Unabsorbed Light from Direct-Drive Implosions*

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A new diagnostic is being fielded to record the unabsorbed laser light from implosions on OMEGA. Unabsorbed light from each of the 60 OMEGA beams is imaged as a distinct "spot" in time-integrated charge-coupled–device camera images filtered to collect the 3ω (351-nm) laser wavelength. Each spot is, in essence, the ending point of a beamlet of light that originates from a specific region of a beam profile. The beamlet enters and exits the coronal plasma of the target, following a path determined by refraction. The intensity of light in the beamlet varies along that path as a result of absorption and cross-beam energy transfer (CBET) with other beamlets. Ray tracing identifies which laser beam is the source of the collected beamlet creating each spot and from where in that beam's profile the beamlet originated.

This diagnostic enables the detailed investigation of the effects of CBET on specific locations of the beam profile. A pinhole was used to isolate specific beamlets, making it possible to measure the time-resolved spectrum of the beamlet.

A fully 3-D CBET hydrodynamics code postprocessor was used to model the intensity and wavelength of each beamlet as it traverses the coronal plasma to the diagnostic. The model predicts that if a single beam in a symmetric implosion is turned off, the recorded intensity of nearby spots will decrease by ~15% as a result of loss of CBET from the dropped beam.

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Quantifying the Growth of Cross-Beam Energy Transfer in Polar-Direct-Drive Implosions*

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Spatially varying cross-beam energy transfer (CBET) was isolated in polar-direct-drive experiments on OMEGA by measuring the angularly resolved mass ablation rate and ablation-front trajectory. Adding a thin layer of Si over a CH shell generates two peaks in time-gated x-ray self-emission images[1]. The location of the inner peak is related to the position of the ablation front and the outer peak corresponds to the position of the interface of the two layers in the plasma. The emergence of the second peak is used to measure the burnthrough time of the outer layer, giving the average mass ablation rate of the material. The mass ablation rate was measured by varying the thickness of the outer silicon layer.

Two-dimensional hydrodynamic simulations that implement a nonlocal electron transport and a CBET model show good agreement with the mass ablation rate and ablation-front trajectory measurements at the pole of the implosion, but the simulations overpredict the mass ablation rate and ablation-front trajectory at the equator. Variations in the nonlocal model do not simultaneously match the measurements on the pole and the equator, but a multiplier on the CBET gain preferentially modifies the laser beam absorption along the equator and excellent agreement with all observables is obtained.

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The Effects of Beam Incoherence and Colors on Cross-Beam Energy Transfer*

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The direct-drive method of inertial confinement fusion (ICF) relies on the efficient coupling of laser energy to the target plasma irradiated by multiple incoherent laser beams. In ICF experiments on the OMEGA and National Ignition Facility (NIF) Laser Systems, the overlapped intensity of laser beams is high enough to make the effect of cross-beam energy transfer (CBET) very important for the balance between scattering and absorption of laser light[1].

CBET is a result of laser–plasma interaction (LPI) via the low-frequency plasma response (in the ion-acoustic-resonance domain). These ion-acoustic resonances can be detuned by the laser beam incoherence in ICF experiments: incoherence in space (caused by distributed phase plates) and/or in time (caused by smoothing by spectral dispersion and possibly multiple colors). To account for these incoherence effects, full LPI modeling with non-paraxial wave propagation[2] for laser beams and low-frequency waves was carried out.

The dependence of CBET on beam intensities, angles of incidence, and frequency detuning (colors) are studied, including interaction in dense plasmas near the beam turning points. The results of the full LPI modeling of CBET are compared with the results of the ray-type modeling of CBET used in large-scale simulations with hydrodynamic codes[3].

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Effects of Cross-Beam Energy Transfer on Scattered-Light Spectra from OMEGA and National Ignition Facility Implosions*

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Cross-beam energy transfer (CBET) can redirect incident laser energy to partially or completely miss directly driven implosion targets. This process has been identified via comparison of experimental scattered-light spectra with scattered-light spectra predicted by the hydrodynamic codes *LILAC* and *DRACO*. Various methods have been proposed to mitigate CBET and efforts are underway at the Laboratory for Laser Energetics to assess these efforts experimentally by changing the relative size of the beams and target diameters. We will present experimental results for different distributed phase plate campaigns using identical targets and different target diameters using identical phase plates. The current models implemented in *LILAC* and *DRACO* are generally in very good agreement with experimental data. Spectral data for thin, mid- and high-Z outer target layers do not appear to significantly alter the scattered-light spectra.

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Exploring the Scaling of Missing Energy and Backscatter with Hohlraum Gas Fill, Case/Capsule Ratio, and Pulse Length*

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Recently there has been interest in using hohlraums with little or no gas fill. This has primarily been driven by the success of implosions with HDC ablators using relatively short laser pulses (6-9 ns) to heat near vacuum hohlraums (NVHs) with a hohlraum fill of 0.03 mg/cc He[1]. These experiments have demonstrated low backscatter, good propagation of the inner beams to the wall, and effective radiation drives that are much closer to high flux model[2] predictions. In contrast, experiments using CH or HDC capsules driven by hohlraums filled with 1-1.6 mg/cc of He have shown large amounts of inner cone backscatter, poor inner cone propagation, and 20-30% “missing energy” relative to the high flux model. However, the NVH is not without challenges. By removing the hohlraum gas fill, whose primary purpose was to control wall expansion and thus limit the time-dependent laser spot motion, the plasma evolution is much more dynamic, making the symmetry difficult to predict.

A series of experiments has been undertaken to systematically explore this marked transition in hohlraum performance, and to move toward an ability to find an optimum gas fill for a given pulse and hohlraum scale combination. Our hypothesis is that initial gas fill, pulse length, and hohlraum case/capsule are important in determining this transition. Finding an intermediate gas fill density that is energetically efficient is of great interest because an ignition design at 0.6 mg/cc with good low-mode symmetry has already been found.[3] In the first set of experiments, in 2014, we found that 0.6 mg/cc fill in a 6.72-mm diameter hohlraum heated by a 6.7 ns 2-shock HDC laser pulse was near optimal because it had the high drive and low backscatter of the companion NVH shot, but also had the symmetry predicted by the rad-hydro code. In follow on experiments in 2015 we are exploring a range of fill densities from 0 to 1.6 mg/cc in a smaller 5.75-mm diameter hohlraum heated by a 6.5 ns 2-shock laser pulse. We will compare the observed changes in drive multipliers and backscatter to those predicted by competing models.

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Reduced convergence implosions using liquid layer wetted foam capsules on the National Ignition Facility*

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A new experimental platform is under development for NIF to that allows for lower hotspot convergence ratios (CR~15) than conventional capsules with DT ice fuel layers (CR~30). Using a liquid fuel layer, this platform makes it possible to select the hotspot convergence ratio through the adjustment of the initial DT vapor density. By lowering the convergence ratio, it is predicted that capsule implosions will become less sensitive to hydro-instabilities and low-mode drive asymmetry[1]. Moreover, the hotspot formation process is expected to become more robust, since the most of the hotspot will be created from mass originating in the DT vapor. In contrast, a traditional ice-layered capsule must form the hotspot by dynamically melting a thin layer from the DT ice during the course of the implosion. Thus, liquid layer wetted foam targets are expected to provide a more predictable 1D-like implosion that is more tolerant to capsule roughness and radiation drive anisotropy.

New target fabrication capability allows for growing a thin low-density (~35 mg/cc) foam on the inside of a high density carbon (HDC) capsule[2]. The fuel layer is then created by wetting the foam with cryogenic liquid DT. Vapor densities of 0.6 to 4 mg/cc are possible by varying the cryogenic fielding temperature from approximately 20 to 25 Kelvin. Due to the short laser pulse lengths made possible by the use of the HDC ablator, these wetted foam capsules will be fielded in high-efficiency near vacuum hohlraums with a He fill of 0.032 mg/cc.

Here, we present an overview of the first experiments planned on NIF using the liquid layer platform. A series of sub-scale experiments will first be fielded, to test the controllability of the hotspot convergence ratio as well as the predictability of the implosion performance. A detailed analysis of the capsule stability properties of these targets is given. A full-scale wetted foam target design is also presented, with the goal of creating a platform with significant α-heating and thermonuclear burn at a modest convergence ratio of ~20.

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Hot Spot Dynamics in Shock Ignition

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We will present preliminary analytic results that describe the temporal evolution of the central hot spot during the implosion and ignition phase of shock-ignited inertial confinement fusion pellets. The propagation of the shock through the hot spot is described via a self-similar Guderley solution, coupled to equations of conservation for both the hot spot and imploding shell. This allows us to determine the required strength of the igniting shock as a function of the thermodynamic parameters at deceleration onset. We will then compare our results with published results that follow an energy balance approach[1]. Finally, we will estimate the sensitivity of the results on the mean-free-path of alpha particles.

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Wave Bowing and Modulational Instability of Ion Acoustic Waves in 2D Vlasov simulations†

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We present 2D+2V Vlasov simulations of Ion Acoustic waves (IAWs) driven by an external traveling-wave potential, $\phi_0(\mathbf{x},t)$, with frequency, ω, and wavenumber, $\mathbf{k}$, typically chosen to satisfy the linear kinetic dispersion relation. Both electrons and ions are treated fully kinetically. Simulations with $\phi_0(\mathbf{x},t)$, localized transverse to the propagation direction, model IAWs driven in a laser speckle as previously done with EPWs.[1] The waves bow with a positive or negative curvature of the wave fronts that depends on the sign of the nonlinear frequency shift[2], $\delta\omega_{nl}$, which is in turn determined by the magnitude of ZT_e/T_i where Z is the charge state and $T_{e,i}$ is the electron, ion temperature.[3] Electrons trapped in an IAW produce a positive frequency shift while ions produce a negative shift. For $ZT_e/T_i >>1$, very few ions are trapped and $\delta\omega_{nl} >0$. If $ZT_e/T_i << 10$, enough ions are trapped to produce an overall negative shift, *i.e.* $\delta\omega_{nl} <0$. Electrons and ions that transit across the wave with a velocity component near the IAW phase velocity take energy out of the wave. Without external support, large amplitude localized IAWs are found to persist for a long time if $ZT_e/T_i >>1$.

We also present simulation results for an IAW transverse modulation instability driven by trapped particles for a variety of ratios of ZT_e/T_i. Here, a plane wave driver $\phi_0(\mathbf{x},t)$ is used with periodic boundary conditions for the particles.

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Kinetic Effects in Inertial Confinement Fusion*

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Recent exploding pusher experiments reveal substantial kinetic effects on the implosion performance. Specific mechanisms potentially responsible for these observations include the inter-ion-species diffusion and reactivity reduction due to ion tail depletion. Theoretical investigation of these groups of effects will be presented. First, evaluation of diffusion in multi-component plasmas will be outlined and the key novel features absent in neutral gas mixtures, such as electro-diffusion and thermo-diffusion, will be discussed. Extension of the developed approach to include ion correlations will be presented and its most important consequences such as vanishing of thermo-diffusion in substantially coupled plasmas will be discussed.

Next, a first-principle approach to evaluating the suprathermal ion distribution function in the ICF hot-spot and semi-analytical solution for this distribution will be demonstrated. Application of this technique to the cases with complicated geometries will be discussed. In particular, hydro-instabilities about the hot-spot/pusher interface will be shown to substantially aggravate reactivity reduction. In addition to this, ion tail depletion will be shown to result in the experimentally observed temperature being lower than the actual one, a novel kinetic effect that may underlie the discrepancy between the exploding pusher experiments and rad-hydro simulations and partially explain the observation that DD temperature is lower than DT temperature at NIF.

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2D Simulations of 3D-Printed Ignition Double-Shell Targets*

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Presently, a renewed multi-lab effort is underway to revisit double-shell targets as an additional venue for ignition. Double-shell targets, consisting of a high-*Z* (typically gold) inner shell concentrically supported by a low-density foam inside a low-*Z* outer-shell ablator, are attractive due to the relative ease on laser and fielding requirements. The original design[1] was shown to be highly unstable to the growth of perturbations on the outer surface of the inner shell. A mechanism involving the recompression of the outward expanding inner-shell, due to hohlraum preheat, by the converging outer ablator was identified as the primary cause for inner-shell breakup due to Rayleigh-Taylor instabilities. Several new designs to mitigate this ignition failure were proposed and proven to be stable via highly-resolved computer simulations[2]. The most promising was a bi-metallic density-graded inner shell supported by a material matching metallic foam[3]. Building on this concept and taking advantage of the latest developments in additive manufacturing that could lead to the development of interface-free targets, a new double-shell design is being investigated[4]. The standard process to manufacture ICF targets uses the inside-outside approach by building spherical targets using layer deposition. To assemble double-shells, the outer ablator needs to be split to allow for the concentric placement of the inner shell. Thus, an equatorial joint is created as the two outer-shell hemispheres are glued together, raising concern over an additional seed for instabilities. Avoiding these issues have made additive manufacturing an attractive approach to building double-shell targets. However, at the present time, objects using this technique are built by depositing material in planar layers of controllable thickness ($\geq$ 40 nm to date). The possibility of introducing micro-density variations at the different "printing" sheets, as well as variations in density across layers has the potential for seeding instability growth. To assess the allowable degree of density variations for a stable double-shell target implosion, we have undertaken an extensive computational study using the radiation-hydrodynamics code HYDRA. Furthermore, sensitivity to untested equations of state of low-density nanoporous foams is assessed by comparing simulations using a variety of constitutive models. In this paper we present the results of our simulations and describe possible future directions.

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Laser-generated magnetic field characterization on the nanosecond timescale

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Application of controlled multi-Tesla external magnetic fields to High Energy density (HED) science experiments allows for new inertial confinement fusion (ICF) designs[1] as well as improvements in the scope of existing HED experiments[2]. Laboratory astrophysics (could add a reference to the Science paper by Remington – 2009 or thereabout) is starting to benefit from the capability of applying controlled B-fields[3].

There are at least two methods for applying controlled B-fields to HED laser experiments. The first method uses pulsed-power to drive multi-kilo-Ampere current through conducting coils[4]. This method is straightforward but requires the engineering and construction of the pulsed-power system. A Second method uses laser-generated hot electrons to source a current which then flows through a loop that can be incorporated into the target[5]. This method can be easily used on any laser facility with two or more beams. A limited number of experiments studying this technique have provided important understanding into the complex physics which determine its operation. However, there is still much to understand to make the technique predictable.

We have performed a series of experiments using the Jupiter Laser Facility to carefully characterize the time-dependent hot electron current which develops between the emitter and collector plates of the laser-driven B-field target. The experiment also explores how the resulting B-field depends on target geometry. The laser-generated plasma is characterized using interferometry and Thomson Scattering. Generated electron current is measured for increasing laser intensity. Finally, the amplitude of the magnetic field is measured inside of the loop with Faraday rotation and outside of the loop with B-dot probes. We will describe the experimental results and implications for improving predictability of this laser-driven B-field technique.

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CBET Experiments at the Nike laser*

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Cross-beam energy transport (CBET) experiments are being planned at the Nike krypton-fluorine (KrF) laser at NRL. This laser has unique characteristics that allow parametric studies. These features include short wavelength (248 nm), large bandwidth (~2-3 THz), beam smoothing by induced spatial incoherence (ISI), and full aperture focal spot zooming during the laser pulse. Nike also has a unique beam geometry that combines two widely separated beam arrays (145^o in azimuth) with close beam-beam spacing (as low as 3.5^o) within the main drive array. Particularly relevant for the CBET studies, recent campaigns have demonstrated the capability to alter the laser bandwidth by a factor of ~10 as well as shifts in the peak laser wavelength. Current plans include investigations with two types of targets: solid cylindrical shells and large volume low-density targets (gas bags and low density foams). The former type of target will investigate the dependence of CBET with gradient geometries more relevant to realistic pellets while the latter will investigate the interaction over a larger, more uniform region. New diagnostics are being fielded based on simulations and previous scattered light measurements at Nike.

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Effects of magnetization on fusion product trapping and secondary neutron spectra*

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Magnetizing fusion fuel in inertial confinement fusion systems can relax required stagnation pressures and densities dramatically. This is due primarily to enhanced thermal insulation of the hot fuel from the cold pusher and to substantial magnetic confinement of charged burn products, facilitating self-heating. Here, we report on a comprehensive theory of this trapping in radially-varying, cylindrical deuterium plasma with an axial magnetic field and minority metal pusher contaminants[1,2]. Using this theory, we demonstrate that secondary fusion reactions can be used to infer the plasma magnetization during fusion burn. Both overall secondary DT neutron yields and their energy spectra contain valuable information about the magnetization of 1 MeV DD tritons, which are exemplary surrogates for 3.5 MeV DT alphas. Using this method, we analyze data from recent Magnetized Liner Inertial Fusion (MagLIF) experiments, providing the first experimental verification of charged burn product magnetic confinement facilitated by compression of an initial seed magnetic flux.

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Multi-dimensional dynamics of stimulated Brillouin scattering and seeded two-ion-wave decay in laser speckle geometry*

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A striking feature of three-dimensional VPIC[1] particle-in-cell simulations of stimulated Brillouin scattering in laser speckle geometry is that the ion acoustic waves (IAW) often exhibit structure in the laser polarization plane that is anti-symmetric across the speckle axis. A simple analytic model is provided that may explain these features as the result of a two-ion-wave decay instability[2] seeded by electron density perturbations from the pump laser field in finite speckle geometry.

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Laser Plasma Interactions with Temporal Bandwidth

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We are performing particle-in-cell simulations using the code OSIRIS to study the effects of laser plasma interactions in the presence of temporal bandwidth under conditions relevant to current and future experiments on the NIKE laser. Our simulations show that, for sufficiently large bandwidth, the saturation level, and the distribution of hot electrons, can be effected by the addition of temporal bandwidths (which can be accomplished in experiments using beam smoothing techniques such as ISI). We will show some preliminary results and discuss future directions.

*This work conducted under the auspices of NRL.

Role of shock-timing in two-shock platform

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Two-shock platform has recently been developed on NIF by LLNL in collaboration with LANL. In present work we discuss the results of the simulation study that investigated the role of shock-timing and the location of shock coalescence in this newly developed platform. It is generally believed that the location of shock coalescence plays an important role in implosion performance of single-shell capsules with strong acceptance that coalescence of the shock in the gas produces higher yield than shock coalescence in the shell. The typically cited reasons for that are lower shell entropy, larger convergence ratio, better hot-spot assembly, and lower amounts of shell material mixing into the fuel. Using HYDRA [2] and RAGE [3] with BHR [4] we studied implosion performance of four cases: (1) nominal two-shock (shocks coalesced in the shell), (2) gas coalescence (second shock delayed by 0.5 ns), (3) high energy (first shock energy increased by 10%; shocks also coalesced in gas), and (4) low energy (second shock delayed by 0.5 ns, but first shock energy reduced by ~10%; shocks coalesced in shell). We utilized separated reactants concept [5, 6] to concurrently investigate the effect of shock coalescence on mix. The capsule was modeled as having a GDP with 1% Si doped shell filled with tritium while two microns of the shell were deuterated. For both case when the shocks coalesced in the gas the performance improved by ~50% while the acceptance energy was only slightly higher (~3%). This suggests that improving shock timing can increase the neutron yield without a significant increase in the drive. The picture of how the mix changes with variation in shock timing and whether there are significant differences in the mixed mass between the gas coalescence case and the shell one is not as crisp as the overall performance. In particular, according RAGE with BHR, the mix mass is lower for the gas coalescence case (by ~5%) and higher for the high energy case (~3%) relative to the nominal one, despite the fact that for both of these cases the shocks coalesced in the gas. On the other hand, the DT yield, which is used as a measure of mix, noticeably increases when the shock coalesce in the gas due to prevalence of higher temperatures in the mixed region. So perhaps the mix mass is more sensitive to the strength of the shocks rather than the location of their coalescence. We strongly believe that this simulation study will benefit current HED/ICF efforts such as mix and burn experiments and wetted-foam concept [7] which plan to use two-shock platform on NIF. It will deepen our understanding of the role that the shocks and the location of the calescence play during the implosion and allow us to examine if the separated reactant capsule concept provides a well diagnosed mix platform for this two-shock experiment.

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Zakharov Modeling of Thomson-Scattering Measurements of Multibeam Two-Plasmon Decay*

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Many-beam laser facilities introduce laser–plasma interactions where multiple beams can couple to common daughter waves. Recent theory, modeling, and experiments have suggested that multiple laser beams can drive the two-plasmon–decay (TPD) instability through common electron plasma waves, and these waves, when driven to large amplitudes, lead to the onset of turbulence. Experiments on OMEGA using ultraviolet Thomson scattering measured the amplitude of common electron plasma waves driven by multibeam TPD and corresponding electron plasma waves excited by the Langmuir-decay instability. Simulated Thomson-scattering spectra from 3-D numerical solutions of the extended Zakharov equations of TPD using the realistic multibeam laser geometry, including phase plates and polarization smoothing, are in excellent agreement with the measured relative wave amplitudes of the primary TPD-driven waves and the Langmuir-decay daughter waves. This encouraging result suggests that the Zahkarov model includes the relevant physics to capture the TPD-driven electron plasma wave amplitudes in this turbulent regime. A hybrid-particle technique was used along with the electron plasma wave fields calculated by the Zahkarov model to accelerate electrons and calculate the hot-electron spectrum.

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Planar Two-Plasmon–Decay Experiments at Polar-Direct-Drive Ignition-Relevant Scale Lengths at the National Ignition Facility*

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Polar-direct-drive (PDD) inertial confinement fusion, in which capsules are irradiated directly with a laser, is the only alternative approach to achieving ignition at the National Ignition Facility (NIF). Under these conditions, laser–plasma instabilities such as the two-plasmon–decay (TPD) instability, can lead to significant levels of hot-electron generation, which can be detrimental to implosion performance. We report on the first experiments at the NIF to probe TPD at scale lengths relevant to PDD ignition. The irradiation on one side of a planar CH foil generated a plasma at the quarter-critical surface with a density gradient scale length of $L_{\mathrm{n}} \sim 600\ \mu\mathrm{m}$, an electron temperature of $T_{\mathrm{e}} \sim 3$ keV, an overlapped laser intensity of $I \sim 6 \times 10^{14}\ \mathrm{W/cm^2}$, and a TPD threshold parameter of $\eta \sim 4$. The K_α emission from a buried Mo layer was measured to infer the total energy in TPD hot electrons, while the slope of the hard x-ray spectrum was used to infer the hot-electron temperature. Optical emission at $\omega/2$ correlated with the time-dependent hard x-ray signal confirms that TPD is responsible for the hot-electron generation. The effect of laser beam angle of incidence on TPD hot-electron generation was assessed by using only the NIF inner-cone beams (~23° and ~30° relative to the foil surface) in one experiment and only the NIF outer-cone beams (~45° and ~50° relative to the foil surface) in another. This platform will be further developed and used to study TPD thresholds and mitigation strategies relevant to PDD ignition implosion experiments at the NIF.

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Absolute Two-Plasmon Decay and Stimulated Raman Scattering in Direct-Drive Irradiation Geometries*

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It is found that absolute stimulated Raman scattering (SRS) and two-plasmon decay have comparable thresholds for recent OMEGA experiments, so that both may play a role in generating the half-harmonic emission observed in these experiments[1]. The scaling of the two instabilities with plasma parameters and irradiation and polarization geometries are analyzed and shown to be quite different. Consequently, for multibeam irradiation, different beams may contribute preferentially to different instabilities. Examples relevant to recent experiments will be discussed.

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A Three-Dimensional Model for Hot-Electron Generation in Direct-Drive Implosions*

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Hot-electron preheat, caused by laser–plasma instabilities—predominantly two-plasmon decay (TPD)—does not clearly impair the performance of current OMEGA cryogenic implosions. Nevertheless, hot-electron signatures are readily observed and hot electrons can carry as much as ~1% of the incident laser intensity in strongly driven experiments[1]. Such levels of preheat would strongly impact inertial confinement fusion schemes, making it imperative to understand this process, its interaction with cross-beam energy transfer, and its scaling to ignition conditions. For this purpose, a new 3-D model [laser plasma simulation environment (*LPSE*)] has been constructed that takes into account several physical processes that are thought to govern hot-electron generation based on the assumption that TPD is dominant. The model builds on earlier work[2] and uses a new GPU-based hybrid-particle method to describe hot-electron production. The 3-D aspect of these simulations has led to an improved understanding of the TPD instability: the time-dependent hot-electron power, total energy, and energy spectrum are described and found to compare favorably with observations for several different OMEGA experiments.

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Two-plasmon decay instabilities in a plasma with ion density fluctuations

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Previous study found that the two-plasmon decay (TPD) modes in the low density region were important to hot electron generation in direct-drive inertial confinement fusion[1]. These modes were linked to ion density fluctuations generated by the absolute TPD modes and formed the first stage for electron acceleration due to their low phase velocities. Here we investigate the excitation mechanism of these modes by studying linear growth of TPD instabilities in a plasma with ion density modulations under parameters relevant to OMEGA experiments using LTS[2] and also WKB-type fluid simulations. It is found that when a static ion density modulation is added to the linear plasma density profile, the otherwise convective TPD modes become absolute with a growth rate depending on the modulation amplitude and wave number. The maximum absolute growth rate is ~70% of the corresponding homogeneous TPD growth rate, much higher than the convective growth rate without the ion density modulation. This may explain why in Particle-in-Cell simulations these modes were only found in the nonlinear stage when ion density fluctuations were present. The simulation results will be compared with theory[3].

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Dynamic-Bandwidth-Reduction Experiments on the OMEGA Laser*

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To increase the available laser energy, smoothing by spectral dispersion (SSD) can be turned off during the high-power portion of a laser pulse. SSD plays an important role in direct-drive experiments before the conduction zone has had time to develop. Simulations suggest that once the conduction zone has formed, the electron transport to the ablation surface is sufficient to smooth the high-frequency intensity modulations (laser imprint). These simulations indicate that reducing the bandwidth after the first few nanoseconds (dynamic bandwidth reduction) will have a negligible impact on the implosion performance. Dynamic-bandwidth-reduction experiments will be presented, where the SSD is turned on only during the initial part of the laser pulse (the pickets). The implosion performance for three laser-smoothing conditions will be compared: no SSD, full SSD on for the entire laser pulse, and SSD on only during the pickets.

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Channeling Kilojoule Laser Pulses Through Long-Scale-Length Plasmas*

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Channeling experiments were performed that demonstrate the transport of high-intensity (>10^{18}-W/cm^2), multikilojoule laser light through a millimeter-sized, inhomogeneous (~300-μm density scale length), laser-produced plasma up to overcritical density, which is an important step forward for the fast-ignition concept. It was found that the high-intensity light evacuates a conical-shaped cavity with a radial parabolic density profile. Experiments showed that 100-ps infrared pulses with a peak intensity of ~1×10^{19} W/cm^2 produced a channel to plasma densities beyond critical, while 10-ps pulses with the same energy but higher intensity did not propagate as far. The plasma cavity forms in less than 100 ps, using a 20-TW laser pulse, and advances at a velocity of ~2 to 3 μm/ps, consistent with a ponderomotive hole-boring model. The background plasma density and the density depression inside the channel were characterized with a novel optical probe system. The evolution of the channel walls is quantitatively consistent with heating the plasma electrons inside the channel to multi-MeV temperatures. The development of a radial shock wave and the longitudinal channel formation is fully established within a 100-ps time scale. The long duration of the channel and the high plasma temperature inside the channel are advantageous for applications requiring a transmitting plasma waveguide. A benefit of the strong heating in the channel is that the plasma becomes more transmitting for subsequent pulses. The channel-progression velocity was measured for the first time, which agrees well with theoretical predictions based on large-scale particle-in-cell simulations, confirming scaling laws for the required channeling laser energy and laser pulse duration, which are important parameters for future integrated fast-ignition channeling experiments.

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Electron shock ignition of thermonuclear fuel

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Shock ignition uses a late strong shock to ignite the hot spot of an inertial confinement fusion (ICF) capsule. In the standard shock-ignition scheme, the shell is driven at a relatively slow velocity of about 250 km/s and an ignitor shock with an initial pressure ≥300 Mbar is launched by the ablation pressure from a spike in laser intensity. Recent experiments on OMEGA have shown that focused beams with intensity up to 7-8 × 10^{15} W/cm^2 can produce copious amounts of hot electrons. The hot electrons are produced by laser–plasma instabilities (LPI's) (such as stimulated Raman scattering and two-plasmon decay) and can carry up to ~15% of the instantaneous laser energy. These experiments showed that the hot electron production is enhanced in CH ablators with respect to other materials, possibly due to the presence of hydrogen in CH. NIF-scale targets will likely produce even more hot electrons because of the large plasma scale length. We show that it is possible to design ignition targets with implosion velocities as low as 100 km/s that are shock ignited using LPI-generated hot electrons to raise the pressure of the shell up to several Gbar just before stagnation (Electron Shock Ignition, ESI). For moderate hot electron energy (T_{hot} <50 keV), the compressed DT shell can efficiently stop most of the hot electrons. For higher hot electron temperatures, ESI targets feature a mid-Z layer designed to stop the hot electrons up to temperatures of 200 keV. The gigabar pressures in the electron-heated shell drives a multigigabar shock in the hot spot, igniting it with a significant margin for moderate total laser energies.

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Improved fast heating coupling efficiency to laser-compressed deuterated plastic shells via visualization of fast electron transport*

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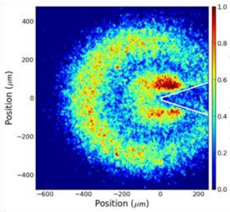
We report on visualization of fast electron spatial energy deposition in integrated fast ignition experiments and up to 7% short-pulse energy coupling, the highest ever reported from the OMEGA laser facility[1]. We used a new platform combining narrow bandwidth x-ray imaging and spectroscopy measurements with a novel Cu-doped shell target with cone. The shell was driven asymmetrically using up to 18 kJ from the OMEGA drivers resulting in a compressed core which has been characterized extensively[2]. The core was then heated by injecting up to 1.5 kJ short-pulse laser energy from OMEGA EP with varied timing, laser contrast, and cone-tip diameter. We were able to visualize where the short-pulse laser energy, carried by MeV electrons, was eventually deposited via x-ray fluorescence from the core.



The data identified critical components in the integrated fast ignition scheme including shock breakout of the cone-tip and pre-plasma formation inside the cone. With this information we were able to design an improved target, which led to a 4x increase in energy coupled to the core in the latest experiments.

Using a multi-code approach to model the various stages, we were able to reproduce the experimentally measured x-ray emission profiles and yields. This approach can guide modifications to further improve coupling on existing facilities as well as predict performance at the next generation of facilities such as the National Ignition Facility.

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Fast-Electron Temperature Measurements in Laser Irradiation at 10^{14} to 10^{15} W/cm^2*

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The temperature T of the fast electrons in planar-target irradiation using 2-ns UV pulses at 10^{14} to 10^{15} W/cm^2 was measured on the OMEGA EP laser using bremsstrahlung radiation [hard x-ray (HXR)] and K_α radiation from high-Z signature layers. The HXR was measured by a nine-channel filter spectrometer [hard x-ray image plate (HXIP)]. Subtracting the intrachannel background makes it possible to determine the temperature without the need to calculate the Compton scattering. Two types of experiments used K_α radiation. The first used a thick Mo (or Ag) target and the ratio of K_α emitted toward the front and the rear of the target, measured and simulated by a Monte Carlo (MC) code. The ratio decreased with increasing T (since K_α emitted deeper into the foil and therefore absorbed less on the way back out). The second experiment used a target composed of five consecutive-Z layers (Nb, Mo, Rh, Pd, Ag) and K_α lines emitted from the rear of the target (highest Z), measured and simulated by the MC code. For higher temperatures, the K_α energy decreased more slowly with Z. All of these measurements agree with each other.

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Heat-Flux Measurements from Thomson-Scattering Spectra*

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Collective Thomson scattering was used to measure heat flux in coronal plasmas. The relative amplitude of the Thomson-scattered power into the up- and downshifted electron plasma wave features was used to determine the flux of electrons moving along the temperature gradient at three to four times the electron thermal velocity. Simultaneously, the ion-acoustic wave features were measured. Their relative amplitude is used to measure the flux of the return-current electrons. The frequencies of these ion-acoustic and electron plasma wave features provide local measurements of the electron temperature and density. These spectra were obtained at five locations along the temperature gradient in a laser-produced blowoff plasma. These measurements of plasma parameters are used to infer the Spitzer–Härm flux ($q_{SH} = -\kappa\nabla T_e$) and are compared to the values of the heat flux measured from the scattering-feature asymmetries.

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High energy density physics research at SLAC

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Abstract:

The fast progress in laser technology is enabling the exploration of extreme conditions of high pressure and temperature, often found in astrophysical environments, in the laboratory. I will discuss recent results and future perspectives for high energy density physics research at MEC/SLAC and its complementarity with studies being performed at facilities like Omega and NIF. I will focus on the role that laser experiments and ab initio massively parallel simulations are playing in our understanding of the plasma microphysics in these extreme environments.

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SECHEL: a CBET post-processor for hydro codes Recent results and related studies

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In the ICF facilities, many laser beams can overlap in the underdense plasma surrounding the exploded targets. This can lead to energy exchange between beams, which in turn can modify the balance of irradiation around the target and lessen the symmetry of its implosion. The cross-beam energy transfer (CBET) results from the coupling between the beams and the density grating generated by the beam interference pattern. Owing to the large spatial and time scales, and the possibility of non-negligible kinetic effects, modeling the CBET remains a daunting challenge.

At lowest order, our basic tool to study the CBET in hohlraums is the post-processor SECHEL, the characteristics of which will be recalled. This post-processor uses the computation results of the radiative-hydrodynamics code FCI2 to calculate the energy exchange within a stationary description of multibeam interaction. Based on SECHEL, estimates of energy transfer in rugby-shaped and cylindrical hohlraums from recent NIF and Omega campaigns will be presented.

The range of validity of our model in SECHEL is difficult to assess because many approximations have been done. In order to test some of these approximations and to look for specific effects, we have carried out numerical simulations with codes which include more physics. For example, we have observed the complex evolution of two crossing beams in 2D PIC simulations. These results will be analyzed and discussed.

Prefer Poster Session

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Multi-scale Fokker-Planck modeling of α-particle transport in igniting ICF capsules

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We investigate the hydrodynamics and burn of the thermonuclear deuterium-tritium (DT) fuel in inertial confinement fusion pellets, taking into account the expected strongly kinetic nature of the transport of fusion-created α particles. From a detailed analysis of the collisional mechanisms involved, we developed an efficient numerical method to simulate the creation, transport and collisional relaxation of fusion reaction products.

The analysis rests on a two-velocity-scale Vlasov-Fokker-Planck kinetic model[1,2] which is specially tailored to treat fusion products (suprathermal α particles) self-consistently with the thermal bulk. The model assumes spherical symmetry in configuration space and axial symmetry in velocity space around the mean flow velocity. The new model is an extension of the FPion code[3] which is in charge of treating the reacting DT plasma and thermalized α particles.

Compared with fluid simulations where a multi-group diffusion scheme is applied to model α transport, the full ion-kinetic approach reveals significant non-local effects on the transport of energetic particles[4]. This has a direct impact on hydrodynamic spatial profiles during combustion: the hot-spot reactivity is reduced, while the inner dense fuel layers are preheated by the escaping suprathermal α particles, which are transported farther out of the hot spot. The enhanced transport of fusion products due to kinetic effects leads to a significant reduction of the overall fusion yield.

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High-foot NIF beryllium targets with 6.72-mm cylindrical hohlraums with low gas fills*

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For indirect drive inertial confinement fusion, beryllium (Be) ablators offer a number of important advantages[1,2] as compared with other ablator materials, such as plastic and high-density carbon. Be ablator campaign on the National Ignition Facility (NIF) started in August of 2014 and has so far fielded six tuning shots. The first Be cryogenic DT-layered shot is occurring in June of 2015. The campaign is employing the standard 5.75-mm hohlraum with a high-density He gas fill ($\rho_f = 1.6$ mg/cm^3). The initial results are encouraging and demonstrate a somewhat better laser-capsule coupling than observed for similar plastic targets.

5.75-mm high-fill hohlraums generally exhibit a significant amount of the coupling degradation (between 40 and 50%) that manifests as laser energy backscatter and the so-called power multipliers between 0.5 and 0.9 that have to be invoked to match simulations with observations. The degradation is a consequence of nonlinear plasma processes that presently cannot be accurately modeled. In addition, due to relatively small hohlraum-to-capsule radii ratio, implosion symmetry tuning in such hohlraums must rely upon the cross-beam energy transfer (CBET), which also cannot be accurately modeled. Larger, 6.72-mm, low-fill ($\rho_f \leq 0.6$ mg/cm^3) hohlraums present an attractive alternative: they have demonstrated for 7-ns laser pulses the coupling of about 85-90%; and may also be large enough to provide the implosion symmetry without CBET. We have designed a series of high-foot NIF Be targets for such low-fill hohlraums without CBET using HYDRA simulations. The shortest, ~9-ns pulse uses the fuel adiabat >2.5 but is still expected to yield about 10^{16} neutrons; while a ~13-ns pulse is predicted to ignite. This sequence of targets will be used on NIF starting FY16 to scope the hohlraum performance for varying pulse durations and gas fill densities; and the capsule performance for various adiabats in terms of its yield, stability and implosion symmetry.

* This work was performed at LANL, operated by LANS, LLC for the U.S. DoE under Contract No. DE-AC52-06NA25396; and at LLNL, operated by LLNS, LLC for the U.S. DoE under Contract No. DE-AC52-07NA27344.

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Mounting stalk effects on the burn in separated-reactant capsules*

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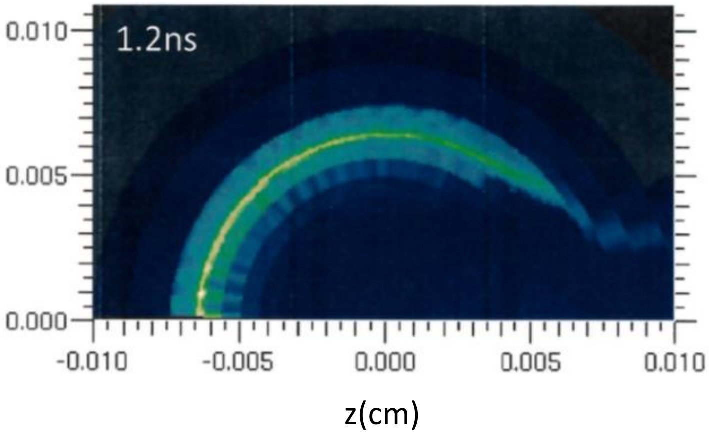
The implosion dynamics of experiments on Omega can be affected if the mechanical support for the capsule, consisting of a mounting stalk and glue spot, becomes too large as shown below in the density image near bang time. These effects are exacerbated for certain classes of experiments, such as separated-reactant capsules, where material from the stalk can be driven into the imploded core resulting in increased mixing of the reactants. We examine these effects on burn for a specific class of separated reactant capsules where a 50/50 HT gas fill is contained within a CD plastic shell. Escaping burn reaction products for these implosions (including TT, DT & DD neutrons, DD protons, and HT & DT gamma rays) have been calculated using the Hydra[1] code. The dependence of these products on the size of the mounting stalk and glue will be shown.



* This research was supported by the US DOE/NNSA, performed in part at LANL, operated by LANS LLC under contract number DE-AC52-06NA25396.

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Application of Imposed Magnetic Fields to Ignition and Thermonuclear Burn on the National Ignition Facility*

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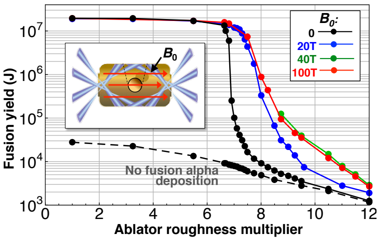
We are studying the impact of highly compressed magnetic fields on the ignition and burn of targets for the National Ignition Facility. Initial seed fields of 30-70 T that compress to greater than 10^4 T (100 MG) under implosion can reduce hotspot conditions required for ignition and propagating burn through range reduction and magnetic mirror trapping of fusion alpha particles, suppression of electron heat conduction, and potential stabilization of hydrodynamic instabilities. This may permit recovery of ignition, or at least alpha heating, in capsules that would otherwise fail due to hydro instability[1]. It may also enable ignition in targets designed for reduced drive or lower convergence ratio.

Initial 2-D simulations for the NIF indirect-drive ignition platform (Fig. 1) show the magnetic field shifts the ignition "cliff" to the right: capsules ignite at shell perturbations that would not without the field. We are also studying magnetic field enhancement of volumetric ignition in room temperature DT-gas capsules, and the effect on hot electron preheat from laser-plasma interactions.



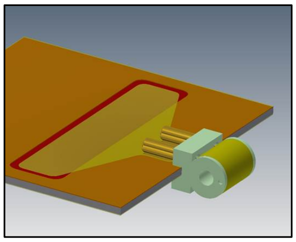


Fig. 1. Fusion yield of NIF cryo ignition target vs. ablator roughness multiplier for seed magnetic field from 0 to 100 T [1]. Fig 2. Hohlraum test coil for field characterization.

We are testing hohlraum magnet coils (Fig. 2) driven by a pulsed power supply that could be fielded in a NIF Diagnostic Insertion Manipulator (DIM). We have achieved axial fields of ~30 T on our way to a nominal design goal of 50 T. Proof-of- principle experiments for magnetized ignition capsules on NIF are now being planned.

* Work performed under the auspices of the U.S. DoE by LLNL under Contract DE-AC52-07NA27344, supported by LDRD tracking number 14-ER-028.

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Ion acoustic wave decay to two daughter waves using a 2D+2V Vlasov code[†]

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The stability of freely-propagating ion acoustic waves (IAWs) is a basic science problem that is made difficult by the need to resolve electron kinetic effects over a timescale that greatly exceeds the IAW period during numerical simulation. IAW decay may play an important role in the long-timescale evolution and saturation of stimulated Brillouin scattering[1,2]. Recent numerical results examining IAW stability using a 1D+1V Vlasov-Poisson solver indicate that instability is a fundamental property of IAWs that occurs over most if not all of the parameter space of relevance to inertial confinement fusion experiments[3].

We present here new results addressing the question of IAW stability in a 2D+2V system using LOKI[4,5]. Our results demonstrate the decay of an IAW into daughter modes with wave vectors non-parallel to the fundamental mode. In addition, a new theoretical approach to obtaining a growth rate for the decay modes in 1D and 2D systems is presented, based on a mode decomposition of the ion Vlasov equation with an adiabatic electron distribution model[6]. This analytic approach is used to obtain quasi-steady state harmonic amplitudes that agree closely with simulations.

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Vlasov Simulation of the Effects of Pitch Angle Collisions in Electron Plasma Waves†

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Kinetic simulation of two dimensional plasma waves through direct discretization of the Vlasov equation may be particularly attractive for situations where minimal fluctuation levels are desired, such as when measuring growth rates of plasma wave instabilities. In many cases collisional effects can be important because they both set a minimum damping rate for plasma waves and can scatter particles out of resonance. Here we discuss Vlasov simulations of the effects of pitch angle scattering on electron plasma waves (EPW). In particular, the effects of electron-ion collisions on the frequency and damping, Landau and collisional, of small-amplitude EPWs for a range of collision rates and wave phase velocities are found in one-dimensional simulations and compared with theory. For this study we use the Eulerian-based kinetic code LOKI that evolves the Vlasov-Poisson system in 2+2-dimensional phase space. Discretization of the collision operator using 4th order accurate conservative finite-differencing will be discussed.

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Three-Dimensional Full-Beam Simulation of Ultrashort Laser Pulse Amplification by Brillouin Backscattering †

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Laser amplification by stimulated Brillouin scattering (SBS) has been previously proposed as a method of achieving high intensity sub-picosecond laser pulses. The 3D fluid simulation code pF3D is used to simulate the SBS interaction of two counter-propagating laser pulses in parameter regimes similar to current experiments.[1,2] The optimal operating regime is explored by variation of the pump and seed intensity, pulse duration, and plasma properties. The sensitivity of seed intensity amplification, pulse compression, and wave front quality are investigated with regards to spontaneous laser beam instabilities such as filamentation and amplified spontaneous emission. The influence of the spatial and temporal coherence of the pump and seed on the amplification process is presented.

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Proton acceleration in the interaction of high power laser and cryogenic hydrogen targets

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High intensity laser driven ion acceleration has attracted great interest due to many prospective applications ranging from inertial confinement fusion, cancer therapy, particle accelerators.

1D and 2D Particle-in-Cell (PIC) simulations are performed to model and design experiments at MEC for high power laser interaction with cryogenic hydrogen targets of tunable density and thickness. Preliminary 1D and 2D simulations, using fully relativistic particle-in-cell code PICLS, show a unique regime of proton acceleration, e.g. ~ 300 MeV peak energy protons are observed in the 1D run for interaction of ~10^{20} W/cm^2, 110fs intense laser with $6n_c$ dense (n_c=10^{21} cm^{-3}) and 2μm thin target. The target is relativistically under-dense for the laser and we observe that a strong (multi-terawatt) charge separation electric field is produced and protons are reflected to high velocities by this field. Further, this field and the laser keep propagating through the hydrogen target and soon meet up with target normal sheath acceleration (TNSA) electric field produced at the target rear edge and vacuum interface and this superposition amplifies the TNSA fields resulting in higher proton energy. In addition, the electrons present at the rear edge of the target continue to gain energy via strong interaction with laser that crosses the target and these accelerated electrons maintains higher accelerating electric fields which further provides acceleration to protons. We will also present detailed investigation with 2D PIC simulations to gain a better insight of such physical process to characterize multidimensional effects and establish analytical scaling between laser and target conditions for the optimization of proton acceleration.

Vlasov Fokker Planck modeling of High Energy Density Plasmas

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Vlasov-Fokker-Planck simulations can be applied to a wide variety of problems in High-Energy-Density Plasmas. Like standard Vlasov codes, they can used to study small timescale kinetic physics such as the waves in plasma media, including Landau Damping, echoes, and instabilities with the added ability to probe the effect of collisions – especially important in high density scenarios. Moreover, when an implicit solver is employed, Vlasov-Fokker-Planck simulations enable the study of kinetic effects in simulations over realistic temporal and spatial problems – important, for example, in examining various transport phenomena. Recent simulations with the VFP code OSHUN [1] will be presented for all of the aforementioned problems. The algorithmic improvements that have facilitated these studies will be also be discussed.

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Ion-kinetic effects in ICF

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The design of ICF capsules has for decades relied on the numerical simulation of their hydrodynamics including numerous additional physical effects (e.g., laser absorption, radiation transfer, atomic physics, kinetic modeling of electron thermal conduction, equations of state, etc...). However, the underlying kinetics of the ions comprising the targets has not received so much attention until recently. Various experimental and theoretical results now suggest that it should be taken into account for achieving ignition and thermonuclear burn.

This was investigated for the first time in the interpretation of implosions of D_2 and D^3He gas-filled microspheres conducted at the OMEGA laser facility through ion Vlasov-Fokker-Planck simulations[1]. Part of the discrepancies between the experimentally recorded target metrics (e.g., implosion timing, yield of nuclear reactions and fuel $\rho.r$) were hereby traced to kinetic modifications of ion transport in addition to the traditionally invoked hydrodynamic instabilities. Independent theoretical modeling of the thermodynamics of those targets[2,3] also suggested that ion-kinetic effects (e.g., species separation) had to be taken into account to reproduce the experimental results.

In targets designed for sizeable thermonuclear combustion[4], which are more collisional and thus should remain closer to hydrodynamical behavior, ion-kinetic effects have nonetheless been shown to explain the disagreement found between evaluations of the ion temperature in the reacting fuel from different nuclear diagnostics[5]. The multi-species kinetic simulations which correctly render those measurements will be described.

More recently, new capsule implosion experiments have been specifically designed to demonstrate the occurrence of ion-kinetic effects[6]. The increasing deviation of hydrodynamical modeling from experimental data as ion-kinetic effects come more and more into play has been rendered by reduced models[7] of those effects, and to some extent by direct kinetic simulations[8] which will be presented. Forthcoming work will focus on the kinetic modeling of the fuel-pusher interaction in those experiments, aiming at better rendering the most strongly kinetic ones.

On the other hand, understanding quantitatively how igniting targets will burn definitely requires an ion-kinetic treatment of energetic particles produced by nuclear reactions. The upgraded kinetic model that was recently designed to that end[9] will be presented. That new code will be used to explore the consequences of ion-kinetic effects on the ignition threshold and the overall thermonuclear gain.

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Off-axis stagnation of a high-Z hohlraum wall onto a capsule ablator: hydrodynamics vs. collisional-PIC modeling

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In a NIF hohlraum, the laser-heated high-Z wall (Au) expands inward as a hot (T> = 1keV) low-density (Ne ~ 1e21/cc) fast moving (v ~ 500 km/s) coronal plasma. At the same time, the ablated material (C) off the capsule expands outward into the laser path with similar plasma conditions. The collision of these two plasmas is partially damped by the gas initially filling the hohlraum (He).
We will discuss this situation through comparisons of radiative-hydrodynamics simulations (HYDRA) and explicit fully collisional Particle-In-Cell simulations of a simplified one-dimensional version of this problem. Emphasis will be put on the transition from a fluid regime to a partially collision-less one as the density of Helium, the material of the wall and the velocities are varied. We will conclude by applying these findings to the Near-Vacuum-Holraum (NVH)[1] used to drive diamond capsule on the NIF and quickly discuss possible forthcoming experimental verifications at OMEGA.

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An Ideal Hohlraum Platform Using Double-Shell Ignition Targets*

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Achieving ignition on the National Ignition Facility with cryogenic single-shells will likely require less drive degradation than is currently inferred, reduced hard x-ray and electron preheat and improved drive symmetry control. For example, the suite of ignition-relevant hohlraums tested to date is challenged by an unexplained loss of drive energy of nearly 15-25%, after allowing for direct backscatter losses. Much of this drive loss correlates with hohlraums filled with a low-*Z* gas to control time-dependent drive non-uniformities from wall motion. At the other end of candidate ignition platforms are the near-vacuum cylinders that show a reduced drive anomaly but an unexplained symmetry behavior. Overall, the hohlraum platforms tested to date show a rich variety of physical effects that have proved challenging to model with mainline simulation tools. The lone exception is the indirect-drive exploding pusher (IDEP) hohlraum platform that gave near ideal 1-D capsule performance due to the relatively short laser pulse length (< 5ns) used and the low fuel convergence (<4) [1]. However, this platform is not a recognized pathway to single-shell hot-spot ignition.

On the other hand, double-shell (DS) ignition targets are well suited to the impulsive drive of an IDEP hohlraum platform. As a reminder, DS's differ from standard hot-spot single-shell targets by a volume ignition mode with low threshold ignition temperatures (~4 keV), high fuel burn fractions (~50%), vacuum hohlraum fielding [2] and high margin to hohlraum flux asymmetry [3]. The challenges with DS's include target fabrication complexity, relatively low energy gain, and sensitivity to problematic mix between the DT fuel and high-*Z* inner shell. However, double-shell performance is less sensitive to peak implosion speed and fuel adiabat, enabling the use of a vacuum hohlraum driven with a short (<4 ns) but high-power laser pulse (~ 500 TW). This paper explores potential designs that could enable DS ignition by use of a simplified IDEP-like hohlraum platform.

*Work performed under the auspices of U.S. Department of Energy by LLNS-LLC under Contract DE-AC52-07NA27344 and supported by LDRD-14-ERD-031.

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Simulating the growth of small perturbations in laser-driven ICF planar targets using the FAST3D code

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Abstract

The realistic modeling of the ablative Richtmyer-Meshkov (RM) and Rayleigh-Taylor (RT) instabilities is essential for viable inertial-confinement-fusion (ICF) pellet designs. In this presentation, we discuss results from recent two-dimensional numerical studies using the FAST3D code at the U.S. Naval Research Laboratory (NRL). The objective of this study is to simulate accurately the evolution in time of laser and surface non-uniformities due to the RM and RT instabilities in planar ICF targets, which historically has been a challenging task for most radiation hydrodynamics codes. Two different scenarios are considered. In the first, we simulate the growth of extremely small, pre-imposed target-surface perturbations in polystyrene (CH) foils that are driven by uniform laser light. By performing a sequence of runs at different perturbation wavelengths, we generate linear dispersion curves (perturbation wavelength versus growth rate), which we then compare with results from R. Betti *et al.* [Phys. Plasmas **5**, 1446 (1998)] that were obtained with the ORCHID code for the same target and laser pulse parameters. In the second class of problems, we consider the growth of perturbations due entirely to laser non-uniformities in directly-driven CH targets. This is accomplished by employing a model of laser imprint in the FAST3D code based on the induced-spatial-incoherence (ISI) method [R.H. Lehmberg and S.P. Obenschain, Opt. Commun. **46**, 27 (1983)] used for beam smoothing on the Nike laser at NRL. An important aspect of this second study is that we also examine the efficacy of thin "high-Z" overcoats such as palladium for suppressing laser imprint growth in CH targets. Although this technique has been demonstrated to work experimentally, a corroborating simulation has, so far, been difficult to obtain. We will present our findings to date on this subject and, additionally, discuss plans for future research.

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PREFER ORAL SESSION

Effects of Long- and Intermediate-Wavelength Asymmetries on Hot-Spot Energetics*

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The impact of intermediate- and low-mode asymmetries on the performance of inertial confinement fusion implosions is investigated by a detailed study of hot-spot energetics. It is found that low- (ℓ ~ 2) and intermediate-mode (ℓ ~ 10) asymmetries affect the hot-spot hydrodynamics in very different ways. It is observed that for low-mode asymmetries, the fusion yield decreases because of a significant reduction in hot-spot pressure while the neutron-averaged hot-spot volume remains comparable to that of unperturbed (clean) simulations. On the other hand, implosions with moderate-amplitude, intermediate-wavelength modes, which are amplified by the Rayleigh–Taylor instability (RTI), exhibit a fusion-yield degradation primarily caused by a reduction in the neutron-averaged hot-spot volume without significant degradation of the pressure. For very large amplitudes, the intermediate modes show a "secondary piston effect," where the converging RTI spikes compress a much smaller volume, allowing for a secondary conversion of the shell's kinetic energy to internal energy at a central region. The signature of these asymmetries on the x-ray emission images from the hot spot (i.e., the hot-spot radius), the neutron-averaged ρR, and temperature diagnostics provide valuable insight to understanding the implosion performance.

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Sensitivity of hot spot properties to the cold DT fuel adiabat and interfacial instabilities*

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We study the dependence of key inertial confinement fusion hot spot simulation properties on the deuterium-tritium fuel adiabat both theoretically and numerically by increasing the energy to the cold shell. Variation of this parameter reduces the discrepancies between simulation and experiment in some, but not all, experimentally inferred quantities. Using simulations with radiation drives tuned to match low-foot experimental shots N120321 and N120405; we carry out sets of simulations with varying amounts of added entropy and examine the sensitivities of important experimental quantities. Calculated neutron yields, burn widths, hot spot densities, and pressures follow a trend approaching their experimentally inferred quantities. Calculated ion temperatures and areal densities of the capsules are sensitive to the adiabat changes, but do not necessarily converge to their experimental quantities with the added entropy. This suggests that a modification to the simulation adiabat in HYDRA may be only one of several factors that are responsible for the observed discrepancies between simulation and experiment. In addition, we use a theoretical model to predict 3D mix and observe a slight trend toward less mixing as the entropy is enhanced (LA-UR-15-22984)

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First-principles based EOS model of carbon for HEDP and ICF applications

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I will describe the construction of a 5-phase EOS model for carbon (including diamond, bc8, simple-cubic, simple-hexagonal, and liquid phases), which covers a wide enough range to be useful for a variety of current HED applications. The various first-principles electronic structure studies (of both the Density Functional Theory and Path Integral Monte Carlo varieties) used to constrain this EOS model will be discussed as well. Special attention will be given to the elucidation of the high-T liquid EOS, and in particular to a new simple model for ion-thermal excitations which seems to fit our computational data better than other models we had used in the past.

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Extended Equation of State of Polystyrene (CH) Based on First-Principles Calculations*

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As an inexpensive and hard plastic, polystyrene (CH) is often chosen as the ablator material for inertial confinement fusion (ICF) capsules. In ICF implosions, polystyrene is normally shocked to high pressures from a few to hundreds of Mbar. The precise knowledge of its static, transport, and optical properties under such high-energy-density (HED) conditions are crucial to ICF target designs. For example, the equation of state (EOS) of polystyrene not only determines the shock strength launched by laser or x-ray drives, but also affects the Rayleigh–Taylor instability growth at the ablation front.

Using first-principles molecular dynamics methods based on density functional theory (DFT), we have performed EOS calculations of polystyrene for a wide range of densities ($\rho = 0.1$ g/cm^3 to $\rho = 100$ g/cm^3) and temperatures ($T = 1000$ to 4,000,000 K). These methods include the orbital-based quantum molecular dynamics (QMD) and the orbital-free molecular dynamics (OFMD). The former method is suitable for high-density and lower-temperature conditions, while the OFMD method extend the first-principles calculations to much higher temperatures as well as lower densities. Our QMD–OFMD results agree well with the available Hugoniot experiments of polystyrene[1]. When compared with the widely used *SESAME* EOS model, our extended EOS table showed up to ~25% difference in pressure and energy, depending on the warm dense plasma conditions[2].

Based on these extended first-principles EOS calculations, we have built a global EOS model of polystyrene in the liquid phase using the free-energy model. Implementing it into our hydrocodes, we will explore and present how this new EOS table of CH affects ICF target performance in integrated radiation–hydrodynamic simulations.

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The Release Behavior of Diamond Shocked to 15 Mbar*

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The response of a material to shock compression is important in an inertial confinement fusion (ICF) implosion, particularly for establishing the adiabat of the implosion during the shock transit phase. Ultra-nanocrystalline diamond (UNCD) is used as an ablator material for ICF experiments at the National Ignition Facility. Both the Hugoniot and the release behavior of the UNCD ablators are needed to accurately model the implosion process and design ignition targets. The OMEGA laser was used to perform experiments in which both UNCD and single-crystal diamond were shocked to 5 to 15 Mbar. The shocked diamond released into materials with known Hugoniots (quartz, 200-mg/cm^3 SiO_2 foam, liquid deuterium, and polystyrene) and the experimental data are used to constrain the release models for the two types of diamond.

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Three-dimensional Single-mode Nonlinear Ablative Rayleigh-Taylor Instability

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The nonlinear evolution of the ablative Rayleigh-Taylor (ART) instability is studied in three-dimensions for conditions relevant to inertial confinement fusion targets. The simulations are performed using our newly developed code ART3D and an astrophysical code AstroBEAR. The laser ablation can suppress the growth of the short-wavelengths modes in the linear phase but may enhance their growth in the nonlinear phase due to the vortex-acceleration mechanism [1]. As the mode wavelength approaches the cutoff of the linear spectrum (short wavelength modes), it is found that the bubble velocity grows faster than predicted in the classical 3D theory. When compared to two-dimensional results, 3D short-wavelength bubbles grow faster and do not reach saturation. The unbounded 3D bubble acceleration is driven by the unbounded accumulation of vorticity inside the bubble. The vorticity is transferred by mass ablation from the Rayleigh-Taylor spikes into the ablated plasma filling the bubble volume. A density plateau is observed inside a nonlinear ART bubble and the plateau density is higher for shorter-wavelength modes.

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PHYSICS AND DESIGNS OF IGNTION CAPSULES USING HIGH-DENSITY CARBON (HDC) ABLATORS: ROBUST DESIGNS, STABILTY, PICKETED PULSES, AND SHOCK MERGES

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The two types of ablators used in most implosion experiments at the National Ignition Facility are HDC and CH. The high density of HDC (3.5 g/cm^3) offers many advantages over CH.[1 - 3] The required W dopant level of 0.3 at. % can now be deposited inside the HDC layer very uniformly.[4] We present three ignition designs with, respectively, 2, 3, and 4-step increases in Tr. The stability behaviors of these designs will be presented. Although the shortest pulse 2-step design has the highest foot level and consequently the highest fuel adiabat of 2.5, it can still deliver 12 MJ of yield and is robust to surface roughness. The 4-step design has the lowest fuel adiabat α of 1.5 but has the highest ablation front Rayleigh-Taylor (RT) growth. Consequently, the overall robustness of the 4-step design is inferior to the intermediate-adiabat 3-step design. However, if the surface roughness can be improved, then the 4-step design becomes the most robust design since the low adiabat gives it the highest 1D margin. A 2-step design for current implosion experiments using near-vacuum hohlraums, based on the ignition 2-step design, will be presented.

RT growth at the ablation front can be reduced by introducing a picket at the beginning of the pulse.[5] For the 3-step design, the ignition cliff is governed by deceleration phase RT growth at the hot spot perimeter. This RT growth can be reduced by merging the 1st and 2nd shock inside the fuel layer, near the fuel-gas interface.[6] Merging the shocks raises the fuel adiabat but this increase does not offset the rapid decrease of the RT growth. For example, if the 1st and 2nd shock merges at a radius corresponding to 13% of the fuel mass from the fuel-gas interface, then the α increases from 2.05 to 2.27, while yield drops by only 9% and the RT growth factor at the hot spot perimeter drops by half at mode 16.

Merging the 1st and the 2nd shock of the 3-step design at even larger radius, e.g. at the ablator-fuel interface, raises the α to about 4 which lowers the yield but has the advantage of essentially eliminating the mix at the ablator-fuel interface and lowers the convergence ratio to below 25. The merging of the 1st and 2nd shocks generates a strong rarefaction wave. When this wave reaches the ablation front, a strong shock is launched. Introducing a plateau in the Tr profile at this time eliminates this shock and improves the overall performance.

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Adventures in ICF with magnetic fields

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Pulsed-power-driven and magnetized laser-driven targets are attractive alternatives compared to the mainline indirect-drive path for inertial confinement fusion (ICF). The magnetized liner inertial fusion (MagLIF) concept has produced thermonuclear fusion yields using pre-magnetized cylindrical liner targets, a TW-/kJ-class laser to preheat the plasma fuel, and implosion of the solid metal liner using the Z facility. Integrated magnetohydrodynamic simulations provided the design for the first neutron-producing experiments using capabilities that presently exist, namely, DD fuel, 2 kJ of 2ω laser energy, B_z=10 T, and peak current ~19 MA. The initial experiments measured stagnation radii $r < 75$ μm, temperatures around 3 keV, inferred alpha-particle magnetization parameters of $R/R_L \sim 1.7$, convergence ratios in excess of ~40, low levels of beryllium liner mix (0-20%), and isotropic DD neutron yields up to $2*10^{12}$ from implosions reaching peak velocities of only 70 km/s over 60 ns. Quantitative comparison between experimental observables and post-shot simulations will be discussed. Focused laser-only experiments have revealed lower levels of energy coupled to the fuel than desired, and the low-preheat hypothesis is sufficient to explain the measured yields. Experiments involving magnetized laser preheat are being conducted in tandem at the OMEGA-EP facility, where beam smoothing and larger amounts of 3ω laser energy are available, and designs for similar experiments at the NIF will allow for the evaluation of high-gain MagLIF preheating concepts at-scale (~30 kJ from one quad) in late 2015. Magnetic fields have also recently been employed in joint LANL-LLE experiments at the OMEGA facility to increase the plasma electron temperature in gas-filled hohlraums, in agreement with simulations, indicating there may be potential for performance improvement. Finally, the OMEGA facility has shots allocated in 2015 for "mini-MagLIF" direct-drive shots in which most of the beams are used to implode a pre-magnetized CH cylinder containing DD fuel, but one beam is used on-axis to preheat the fuel. Integrated design simulations show measurable yield may be achieved in the first experiments of the concept. In summary, a national effort is underway to evaluate the role of magnetic fields in various target designs. Particularly for MagLIF, flux compression enables trapping of fusion-produced alpha particles and the reduction of the required stagnation pressure to reach ignition conditions from ~375 Gbar in traditional indirect drive to ~25 Gbar with B_z~50-250 MG (~1 Gbar and $\langle B_z \rangle$ ~91 MG have been inferred in experiments to-date).

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Ion-kinetic simulations of D^{3}He gas-filled ICF target implosions with moderate to large Knudsen number

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Recently performed implosion experiments which were specifically designed to demonstrate the occurrence of ion-kinetic effects[1] exhibit an increasing deviation from hydrodynamical modeling as the ion-ion collision mean-free-paths increase relative to the experimental scale size. Those experiments involved silica microspheres filled with equimolar D^{3}He gas at room temperature, imploded by a strong shock driven by an intense 0.6 ns laser pulse at the OMEGA laser facility. The increase in Knudsen number in those targets was obtained by decreasing the fill pressure, thus increasing the collision mean-free-paths. Several physical quantities were recorded by the diagnostics of those experiments, including the yield of the DD and D^{3}He nuclear reactions and Doppler-broadening-inferred burn-averaged ion temperatures in the fuel. Anomalous trends relative to hydrodynamic predictions were observed in these quantities as a function of both Knudsen number and relative concentration of the D and ^{3}He ion species

This behavior has been tentatively rendered by reduced models[2] of ion-kinetic effects, but a deeper understanding of the mechanisms at work requires genuinely kinetic simulations. In this paper, we will present the first results of such an investigation, performed with the ion Vlasov-Fokker-Planck code FPion[3]. Two different values of the initial gas density in the shell were used in those simulations, namely a high value ($\rho = 3.3$ mg/cm^3) for which experimental data is reasonably well described by a hydrodynamic model including ion diffusion, and a low value ($\rho = 0.4$ mg/cm^3) for which the data suggest that the fuel ion species remain unequilibrated for dynamically relevant timescales. As in previous studies[4] the D^{3}He gas was treated by a two-species kinetic formalism with boundary conditions at the fuel-pusher interface taken from hydrodynamical simulations.

Detailed results will be shown. In summary, the kinetic simulation is found to accurately render the moderate discrepancy in the high density (low Knudsen number) case, but in the more kinetic case, although the simulation results are closer to the experiment, there is still some unresolved discrepancy. From an analysis of the distribution functions computed in the fuel, this is obviously to be attributed to kinetic effects at the pusher-fuel interface and in the pusher itself, which are not taken into account in the present work.

Forthcoming work will focus on an improved kinetic modeling of the fuel-pusher interaction in those experiments, aiming at better rendering the most strongly kinetic cases.

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Saturation of Cross-Beam Energy Transfer for Multi-Speckled Laser Beams*

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Cross-beam energy transfer (CBET) is the process by which two crossing laser beams transfer energy between one another through stimulated Brillouin scattering (SBS). Understanding the nonlinear saturation of CBET, including the effects of wave-particle interaction and speckle geometry, is important to controlling low-mode asymmetry in ICF implosions. Nonlinear saturation of SBS in speckled laser beams has been examined in the kinetic regime using 2D and 3D VPIC simulations. Rapid SBS saturation is found to be caused by ion acoustic wave (IAW) bowing resulting from trapped-particle nonlinear frequency shifts and IAW break up in the direction transverse to the laser[1,2].

In this work, VPIC simulations of the nonlinear saturation of CBET for multi-speckled laser beams crossing at arbitrary angles will be reported. In addition to the CBET saturation dynamics by stochastic ion heating studied previously[3] (a process occurring on ~ns-time scales), these simulations show CBET saturating on a faster (~10s ps) time scale. The important role of ion trapping on the nonlinear dynamics of CBET will be discussed as well as the importance of retaining speckle geometry, as the highest intensity speckles are amplified most strongly. Moreover, possible implications for inertial fusion experiments with gas-filled hohlraums will be considered, as these nonlinear saturation dynamics, including the excitation of secondary instabilities such as forward stimulated Raman scattering (FSRS), may limit the efficacy of CBET for symmetry control and contribute to capsule preheat from FSRS hot electrons.

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iFP: An Optimal, Fully Implicit, Fully Conservative, 1D2V Vlasov-Rosenbluth-Fokker-Planck Code for ICF Simulation

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Contrary to predictions of radiation-hydrodynamics design codes, the National Ignition Facility has not succeeded in achieving ignition. Recent experimental evidence suggests that plasma kinetic effects may play an important role during Inertial Confinement Fusion (ICF) capsules' implosion. Consequently, kinetic models and simulations may need to be used to better understand experimental results and design ICF targets. We present a new, optimal, fully implicit, and fully conservative 1D2V Vlasov-Fokker-Planck (VFP) code, iFP, which simulates ICF implosions kinetically. Such simulations are difficult to perform because of the disparate time and length scales involved. The challenge in obtaining a credible solution is further complicated by the need to enforce discrete conservation properties.

In our studies, we employ the Rosenbluth formulation for the Fokker-Planck collision operator. Our approach uses a fully implicit temporal advance to step over stiff collision time-scales. For the solver, we use a Jacobian-Free Newton-Krylov method with an optimal multigrid-based preconditioning technology. To address the issues of velocity disparity between various species as well as those associated with temporal and spatial temperature variations, we have developed: 1) a velocity space meshing scheme, which adapts to the species' local thermal velocity; and 2) an asymptotic expansion of the Rosenbluth potentials based on the large ratio of thermal speeds of the fast-to-slow species ($v_{th,f}/v_{th,s} >> 1$). We have also implemented a Lagrangian mesh, which allows the physical space mesh to move as the capsule compresses. Finally, we enforce discrete conservation of mass, momentum, and energy by solving a set of discrete nonlinear constraints, which are derived from continuum symmetries present in the VFP equations. Herein, we present some results testing the code capabilities and show preliminary simulations of a plasma shock.

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SYMMETRY OF BERYLLIUM CAPSULE IMPLOSION AT THE NATIONAL IGNITION FACILITY

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We will present results of the beryllium experimental campaign on the implosion symmetry properties of beryllium capsules at the National Ignition Facility. These experiments measure both the inflight and core self-emission implosion symmetry. The inflight symmetry of the ablator before stagnation is measured using a backlight imaging [1] techniques. A copper backlighter was used to measure the transmissions (or backlit absorption) of the copper doped beryllium shells. Images of the x-ray emission from the core around bang time provide a measure the symmetry near peak compression [2]. Both pieces of information about the 2D symmetry is used to infer the drive and velocity uniformity enabling us to adjust the properties of the incident laser, mainly the time dependent ratio of the inner beam cone power to the outer laser beam powers, to achieve proper symmetry of the implosion. Results from these experiments show inner beam propagation is not degraded compared to similar implosions with CH ablators and is corroborated by laser backscatter measurements. Variations in the shape compared with implosions using CH ablators also provides information about the cross beam energy transfer used to adjust the equatorial shape and thus infer information about the differences in plasma conditions near the laser entrance holes. Experimental results and modelling of the implosion shape for beryllium capsules will be presented along with comparisons relative to CH ablators.

We acknowledge the significant effort of the Target fabrication at General Atomics and Lawrence Livermore Labs as well as the effort of the NIF operations crew in the success of this work.

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Controlling Laser-Driven Hohlraums-
Clues from Experiments with Earlier Lasers*

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Better characterized and controlled hohlraums are very important for both implosion and science experiments on NIF. A brief review of some hohlraum and related experiments with earlier lasers is given to search for lessons learned and clues for better understanding NIF hohlraums. For example, surprises associated with heat transport inhibition and improved models for radiation generation have been a recurring theme in indirect drive experiments. In Shiva experiments, the hohlraum filling with plasma with density near .25 n_{cr} was only calculated after inhibited heat transport and improved radiation models were adopted in the design code[1]. Early NIF experiments also led to a change in the heat transport and radiation models. In this case, the heat transport model was changed from one with modest inhibition (which had been used to model Nova experiments) to near classical transport[2]. Most recently, a design model invoking very inhibited transport (at various times and locations) has been proposed for NIF hohlraums[3]. Heat transport is clearly a key and poorly understood issue in the design models. Other recurring themes will also be discussed, including hohlraum filling and its mitigation as well as laser plasma instabilities and their control.

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HOT SPOT DYNAMICS AND IGNITION BOUNDARIES FOR HIGH-DENSITY CARBON (HDC) CAPSULES

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The two types of ablators used in most implosion experiments at the National Ignition Facility are HDC and CH. The high density of HDC (3.5 g/cm^3) offers many advantages over CH.[1 - 3] The required W dopant level of 0.3 at. % can now be deposited inside the HDC layer very uniformly.[4] We present three ignition designs with, respectively, 2, 3, and 4-step increases in Tr.

To obtain a better understanding of the hot spot dynamics and to have an overall view of the 1D and 2D margins of these designs, the hot spot trajectories are compared to the 0D ignition boundaries in the hot-spot Tion and ρR space.[5] The ignition boundaries are influenced by the ρR dependence of α deposition. Our ignition boundary, obtained analytically, agrees well with results from 1 and 2D simulations of marginally igniting capsules. The hot-spot trajectories are also plotted on top of the curves of the generalized Lawson Criterion[6-7] to reveal the ignition margins of our designs. These trajectories will be compared to trajectories from CH high-foot post shot simulations,[8] NIF implosion data, and with magnetized HDC capsules.

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Semi-analytic Knudsen-layer reactivity reduction model for spheroidal cavities*

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Recent papers by Molvig *et al.*[1], Albright *et al.*[2], and others, have presented attempts to estimate the fusion reactivity reduction due to fast-ion losses in homogeneous, perfectly spherical, finite fuel assemblies. The mostly analytic analyses presented in Refs. [1] and [2] provide a transparent and tractable glimpse at the general behavior and scaling of this nonlocal transport mechanism, shedding light on one possible departure of present-day inertial confinement fusion (ICF) experiments from the predictions obtained using modern radiation-hydrodynamics simulations. These kinetic models also serve as a point-of-entry to investigations of nonlocal transport phenomena under more general conditions. Here, we remain focused on Knudsen tail-ion losses, but we add one additional layer of complexity to the formalism of Ref. [2] by allowing for generic oblate or prolate deformations of spheroidal cavities. We derive reduced kinetic ion diffusion equations for the fuel cavities, apply an asymptotic boundary-layer treatment consistent with free-streaming ion losses to a perfectly absorbing boundary, and then calculate global solutions for the Knudsen-depleted ion distribution functions. Finally, we calculate the reduced fusion reactivities for a variety of deformed fuel assemblies and compare them with the perfectly spherical cavity solutions. In doing so, we provide a framework to assess the extent to which asymmetries in ICF fuel assemblies could exacerbate the losses predicted by previous perfectly symmetric models.

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Recent progress on understanding LWFA in the nonlinear self-guided blowout regime

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We report on recent results on LWFA in the nonlinear, self-guided regime [Lu et al. Phys. Rev. Spec. Top. Accel. Beams 10, 061301 (2007)]. The wake is excited in the blowout regime where the normalized vector potential is larger than ~4. The laser is self-guided due to laser energy in the leading edge being locally depleted before it diffracts. In the work of Lu et al., matching conditions for the laser spot size and pulse length were presented as well as scaling laws accelerated electron energy in terms of laser and plasma parameters. These scaling laws were compared against results for a 200TW (6 Joule) laser. Recent advances in PIC modeling, including the quasi-3D and boosted frame techniques now make it possible to study these scaling laws for higher laser intensities and laser energies. The quasi-3D algorithm uses a PIC algorithm on an r-z grid and a gridless description in the azimuthal angle. The fields are expanded in azimuthal harmonics and the series is truncated at a chosen number. We have implemented the quasi-3D algorithm into OSIRIS and here we use it to examine the nonlinear regime for existing and future 15-100 Joule lasers. The OSIRIS results are compared against the predictions of the scaling laws in Lu et al. and excellent agreement is found.

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Laser Absorption at Over-Critical Surfaces

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Absorption of high intensity laser light by matter has important applications to emerging sciences and technology, such as Fast Ignition ICF and ion acceleration. As such, understanding the underlying mechanisms of this absorption is key to developing these technologies. Critical features which distinguish the interaction of high intensity light - defined here as a laser field having a normalized vector potential greater than unity - are that the reaction of the material to the fields results in sharp high-density interfaces; and that the movement of the electrons is in general relativistic, both in a fluid and a thermal sense. The results of these features are that the absorption mechanisms are qualitatively distinct from those at lower intensities.

In previous work[1] we discuss the importance of the standing wave structure in understanding the conversion of laser light into energetic electrons. Here we review that work and present current findings.

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Recent results on laser-plasma interactions in shock ignition

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We report some recent PIC and fluid simulation results on laser–plasma interactions and hot-electron generation in shock ignition experiments on OMEGA. Plasma flow velocity profiles have been implemented in both the PIC and fluid simulations to study SBS and its interactions with SRS and TPD. The 2D PIC simulations show that significantly more hot electrons are generated in a CH-plasma than in a C-plasma, which is consistent with the experimental observations. The effects of H-ions in reducing SBS and raising the saturation level of the plasma waves from SRS and TPD will be discussed.

This work was supported by NNSA under Corporate Agreement No. DE-FC52-08NA28302; by DOE under Grant No. DE-FC02-04ER54789 and DE-SC0012316; by NSF under Grant No. PHY-1314734; and by NSCF under Grant No. 11129503. The research used resources of the National Energy Research Scientific Computing Center.

Efficient ion beams with narrow energy spread from laser-driven relativistic plasma accelerators using giant self-generated plasma fields*

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Table-top laser-plasma ion accelerators seldom achieve narrow energy spreads, and never without serious compromises in efficiency, particle yield, etc. Using massive computer simulations, we identify a self-organizing scheme that exploits persisting self-generated plasma electric (~TV/m) and magnetic (~10^4 Tesla) fields to reduce the ion energy spread after the laser exits the plasma – separating the ion acceleration from the energy spread reduction. Consistent with the scheme, we experimentally demonstrate aluminum and carbon ion beams with narrow spectral peaks at energies up to 310 MeV and 220 MeV, respectively, with high conversion efficiency (~5%). This is achieved with 0.12 PW high-contrast Gaussian laser pulses irradiating planar foils up to 250 nm thick. The ion spectral peak energy empirically scales with laser intensity (I) as $I^{0.5\text{-}0.7}$. These results pave the way for next generation compact accelerators suitable for applications. For example, 400 MeV carbon-ion beam with narrow energy spread required for ion fast ignition is well within the capability of PW-class lasers.

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Numerical Cerenkov instability in LWFA Lorentz boosted frame simulation and relativistic collisionless shock simulation

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A numerical instability known as numerical Cerenkov instability (NCI) arises in Particle-in-cell (PIC) simulation involving plasma that is drifting relativistically on the numerical grids. This unphysical instability is due to the unphysical coupling between the Langmuir modes (including main and aliasing) and electromagnetic mode, and leads to exponential growth of EM fields which destroys the physics of interest. This coupling is inevitable in PIC algorithm when finite grid sizes and finite time step are used. As a result, eliminating the NCI is crucial for the accurate PIC modeling of physics problem involving of relativistic plasma drift, including simulation of Laser wakefield acceleration in the Lorentz boosted frame, and relativistic collisionless shock simulations.

In this talk we will briefly discuss the features of NCI in typical relativistic plasma drift simulation, and the strategies we developed to eliminate them. For complete elimination of the NCI we developed codes that use FFT-based Maxwell solver, including fully spectral Maxwell solver, and hybrid Yee-FFT Maxwell solver. We will use LWFA simulation in the boosted frame, and simulation of relativistically shock as examples to explain how will NCI contaminates the physics in simulations using conventional simulation setups (e.g. using Yee solvers, a special time step, and smoothing and filtering on the EM fields and current), and show how the codes with FFT-based solvers eliminate the NCI in these simulations.

Towards a Robust Plasma Wave Amplifier

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Laser pulse amplification and compression by conventional solid-state laser systems is limited by the damage thresholds of the final compression and focusing optics, requiring very large-diameter beams (>60 cm). Amplification in plasma via stimulated Raman and Brillouin scattering has been proposed to overcome this limitation. While the principle has already been demonstrated by Ren *et al.* [1], Lancia *et al.* [2,3], and various cross-beam energy transfer experiments [4,5], plasma-based laser amplification is still a long way from being a practical, stable, robust and versatile device. In this lecture, I will give an overview of the efforts by my team at Oxford University and the Rutherford Appleton Laboratory to get closer to this goal. First, we are studying the viability of Brillouin amplification compared to Raman amplification, identifying its strengths and weaknesses and mapping out the optimal parameter regime. Second, we are testing the robustness of the Raman amplification scheme to imperfections in the laser and plasma parameters: frequency mismatch, plasma density fluctuations, frequency shifts induced by thermal effects. Third, we are studying Raman amplification at wavelengths different from infrared, in particular soft x-rays (1-10 nm). For these wavelengths, electron-ion collisions start playing an important role in the laser-plasma interactions, altering the parameter window for optimal amplification. I will present our latest results and show how these can be used to guide future experiments.

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Studies on the Saturation Limit of Stimulated Raman Backscattering

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In recent years, stimulated Raman backscattering (SRBS) in plasma has become an attractive candidate for overcoming the hurdles to further increases in laser power and intensity to extreme levels. Feasibility of SRBS lasers was initiated and proved with theoretically studies [1-3] and successful experimental demonstrations [4-7]. Still, despite progresses of more than a decade, maximum amplified pulse energy so far obtained in experiments has been limited to a few millijoules, and the mechanisms constraining the output energy remains to be elucidated.

In this talk, we report on Particle-in-Cell (PIC) simulations which confirm the currently achieved SRBS energy seen in experiments [6,7] is close to its maximum. Guided by analytic models and simulations, we extensively explored the SRBS power and energy limits. Detailed studies of the electron dynamics and their impact on the plasma wave reveal that, loss of coherence in the plasma wave due to spontaneous noise caused the early gain saturation. Based on this discovery, we developed a cascade scheme aiming to reduce the impact from the spontaneous noise, and proved that the saturation barrier for SRBS can be resolved this way.

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Effects of Spontaneous Magnetic Fields on the Propagation of Supersonic Plasma Jets*

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High-Mach-number plasma jets are fundamental astrophysical phenomena. Understanding the spatial structure and temporal evolution of such jets is important for frontier astrophysics and for the basic science of high-energy-density plasmas. To that end, we recently conducted unique, scaled laboratory experiments to observe and quantify, for the first time, several important properties of plasma jets. High-Mach-number plasma jets were generated as a consequence of the collision of two laser-produced plasma plumes, and the experiments were radiographed from side-on direction or two orthogonal directions (side-on and phase-on) using high energy protons. Radiographs of unprecedented clarity revealed how the jets responded to self-generated magnetic fields [resulting from the Biermann battery effect ($\nabla n_e \times \nabla T_e$) around the laser spots] which were "frozen in" the plasma flow and subsequently advected along the jet streamlines. Magnetohydrodynamic (MHD) instabilities, driven by plasma current and by plasma pressure gradients, were observed to have important effects on the jet propagation. We have modeled these laboratory experiments with comprehensive two- and three-dimensional numerical simulations, which in conjunction with the experiments provide compelling evidence that we have an accurate model of the most important physics of magnetic fields and MHD instabilities in plasma jets.

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Oral presentation is preferred.

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Electron Dynamics in High Energy Density Magnetized Plasmas

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Magnetic field phenomena are prevalent in natural and man-made high energy density plasmas. In addition to the application of external magnetic fields, plasmas can be magnetized by self generated magnetic fields that arise due to steep gradients in temperature and density.

The self-generated magnetic fields align themselves in a magnetic reconnection geometry. We show that the magnetic tension can be relieved through a novel magnetic reconnection mechanism driven by heat fluxes rather than currents [*PRL*]. This mechanism is prevalent in plasmas where the thermal energy is higher than the magnetic energy. This can occur in hohlraums where reconnection results in redistribution of the thermal energy. It can also occur naturally in stellar atmospheres and can result in the release of magnetic energy.

Plasma transport is greatly modified in magnetized plasmas (wt > 1). We show that the self-generated magnetic fields of approximately 50 T in hohlraums cause significant anisotropies in thermal energy distributions. The Righi-Leduc and Nernst effect become prevalent in determining electron transport. Through kinetic modeling, we show that part of the magnetic field is generated through a novel mechanism that is introduced due to spatial gradients in the distribution function. Additionally, inverse bremsstrahlung heating of the electron distribution function results in different heating rates, temperatures, and magnetic field generation rates than those predicted by classical theory.

The application of an external field results in thermal energy confinement in the laser energy deposition region due to the magnetization of the plasma and subsequent localization of the transverse heat flow. Kinetic modeling shows that the classical heat flow fails to capture the non-local component of the heat flow, nearly 100% of the heat flow in some regions. Nernst compression of the magnetic field results in increased magnetization and thermal energy confinement.

Ion Thermal Decoupling and Species Separation in Shock-Driven Implosions

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The inertial confinement fusion program relies on hydrodynamic simulations to design and understand the results of experiments. However, recent experimental studies on the OMEGA laser facility have demonstrated that the hydrodynamic assumptions break down for the conditions relevant to the shocked central plasma of the hot spot ignition design[1,2]. Implosions of thin-glass shells filled with various mixtures of deuterium and ^{3}He gas produced nuclear yields that were anomalously reduced by 50% as the deuterium concentration in the fuel was reduced. Implosions with low initial gas density (0.4 mg/cc) additionally presented anomalously constant burn-averaged ion temperatures $\langle T_i \rangle$ as the deuterium fraction was varied. This anomalous $\langle T_i \rangle$ trend was found to be a signature of ion thermal decoupling between the D and the ^{3}He ion species. A model enforcing differential temperatures between the two ion species produced good agreement with the measured $\langle T_i \rangle$ and improved agreement with the nuclear yields. In implosions with high initial gas density (3.3 mg/cc), comprehensive nuclear data was used to infer that the burn-averaged deuterium fraction was reduced from the expected value, implying separation of the deuterium and ^{3}He during the implosion. The amount of species separation observed agrees with hydrodynamic simulations that include a reduced ion kinetic model of ion diffusion[3]; these simulations also recapture the observed yield and temperature trends. Results from experimental campaigns demonstrating the importance of kinetic physics in the evolution of plasmas relevant to the shock phase of ICF implosions are presented. Improved kinetic models of the strongly shocked fuel using a Vlasov-Fokker-Planck code will also be presented at this conference[4].

*This work was supported in part by the U.S. Dept. of Energy, LLNL, LLE, and the NNSA SSGF

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Shock-Induced Mix Across an Ideal Interface*

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Standard radiation-hydrodynamic codes force continuity of the pressure and velocity across an interface and usually avoid mixing across the interface by construction. By contrast, here we will show[1] that a multi-species approach describing the propagation of a strong shock across an unperturbed classical interface predicts that significant amounts of rearward shocked material can advect with the shock front over distances several orders of magnitude larger than an ion-ion collisional mean free path. This novel mechanism for interface mixing is found to scale strongly with Mach number (~M^4) and produces an ion population bunch that penetrates the upstream material at nearly the shock speed. This phenomenon is only present in genuinely multi-species simulations and does not appear in simulations in which a diffusion equation is coupled to a single-fluid equation. Possible implications for recent inertial confinement fusion experiments at the Omega laser facility and ignition capsule designs are conjectured.

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Insights into Proton Radiographic Images of Hohlraums*

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Recent proton radiography images taken down the axis of hohlraums shot on the Omega laser[1] have produced considerable speculation as to the origin of the electric and magnetic fields that cause the complex and diverse patterns observed on the CR39 track imagers. We consider a simple model consisting only of electric fields. In particular, we identify two regions in the hohlraum: a region that corresponds to laser interacting with the critical surface, and a region where the gas and the wall interpenetrate. The E field in the first region arises from the gradient in the electron temperature. The field in the second region is due to the E-field that arises at the interface where the gas and wall materials diffuse into each other. Results from a simple 3D computer model consisting of the fields of the hohlraum, the material opacity of the hohlraum, the proton source, and the detector show that the experimental images are well described by this model. If this interpretation holds, this points to an entirely new diagnostic of the laser-wall interaction region, and more importantly, a diagnostic of the gas-wall interface in a gas-filled (or lined) hohlraum. The former is a surface that current diagnostics like X-ray radiography cannot easily diagnose, whereas the latter is an important surface that hydro codes typically do not calculate well. New experimental designs to test this model will be presented. In addition, we present multi-ion species hybrid LSP[1] simulations, where the ions are treated kinetically and the electrons are treated in the fluid approximation, of the diffusive gas-wall interface.

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Electron Temperature Measurement of NIF Hohlraum Plasmas Using Dot Spectroscopy

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ICF experiments at the NIF use a high-Z hohlraum to convert laser power into a temporally tailored x-ray drive that implodes the fuel capsule and initiates alpha-burn. The laser-hohlraum coupling mechanisms and efficiency determine the velocity, adiabat and symmetry of the implosion. It is important to understand these hohlraum-specific effects in order to improve hohlraums so as to increase the likelihood of ignition. Empirically characterizing the temporal history of the hohlraum plasma conditions, such as the n_e and T_e, at various locations within the hohlraum, will provide insight into the hohlraum x-ray conversion efficiency, dynamic x-ray drive symmetry, temporal development and saturation behavior of cross-beam energy transfer, and laser-plasma interactions with associated hot electron pre-heat. Providing benchmark data will additionally improve predictive radiation-hydrodynamic (RH) hohlraum models.

The first T_e measurements inside a NIF hohlraum, near the laser entrance hole (LEH) region, using temporally resolved K-shell X-ray spectroscopy of a Mn-Co tracer are presented in this talk. Targets used a thin (0.16-0.32 μm) Mn-Co (1:1) dot deposited on top of a thin-walled CH capsule, with the dot co-axial with the symmetry axis of a bottom-truncated hohlraum. In the experiment the hohlraum x-ray drive causes the dot to ablate and expand toward the LEH, constrained by the capsule and hohlraum gas plasmas. As the dot material is heated and ionized, it reaches thermal equilibrium with the surrounding local hohlraum plasma. The recorded x-ray spectra of the Mn-Co dot is used to infer the local T_e in the hohlraum plasma, by using both isoelectronic line ratios and Ly_α/He_α line ratios.[1,2] Measured line ratios are compared to detailed atomic physics simulations using SCRAM[3] for Mn and Co to determine the plasma T_e. Time resovled and time-integrated x-ray images perpendicular to the hohlraum axis and 19° from the dot normal record the dot expansion into the LEH region. Comparison of measured results with RH simulations using HYDRA[4], show that current simulations underpredict T_e in the hohlraum near the LEH. Implications of these results will be discussed.

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

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Measurements of the Conduction-Zone Length and Mass Ablation Rate in Cryogenic Direct-Drive Implosions on OMEGA to Restrict Thermal-Transport Models

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Imaging the soft x rays emitted by the coronal plasma of an imploding cryogenic target directly driven on the OMEGA Laser System is used to measure the shell trajectory and the averaged mass ablation rate of the deuterated plastic. These measurements, coupled with the measurement of the scattered-light spectrum, make it possible to determine the length of the conduction zone and constrain the electron thermal transport. Hydrodynamic simulations that use nonlocal thermal-transport and cross-beam energy transfer (CBET) models reproduce these experimental observables. Hydrodynamic simulations that use a time-dependent flux-limited model reproduce the measured shell trajectory and the laser absorption but underestimate the mass ablation rate by ~10% and the length of the conduction zone by nearly a factor of 2. These results highlight the importance of developing multidimensional hydrodynamic codes that include CBET and nonlocal thermal-transport models to accurately determine the energy flow between the laser-absorption region and the ablation surface, particularly when studying effects that depend on the mass ablation rate.

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Development of Predictive Models of Absorption of High Power Laser Light by Optically-Thick Materials

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The interaction of petawatt (10^{15} W) lasers with optically-thick matter forms the basis for advanced scientific applications such as table-top particle accelerators[1], ultrafast imaging systems[2] and laser fusion[3]. Key metrics for these applications relate to absorption, yet the nonlinear conditions in this regime mean that it is often impossible to predict the fraction of absorbed light f, and even the range of f is unknown. In this presentation, using a relativistic Rankine-Hugoniot-like analysis, we show how to derive the theoretical maximum and minimum of f [4]. These bounds constrain all nonlinear absorption mechanisms across the petawatt regime, forbidding high absorption values at low laser power and low absorption values at high laser power. We then show how to sweep out particular curves through this constrained absorption parameter space. That is, by specifying the dominant mechanism of electronic acceleration, our calculations yield closed analytic expressions for f, as well as for its sub-partitioning into electron and ion energies. We show characteristic scalings of f as a function of the laser driver parameters and unperturbed material density, for a variety of absorption mechanisms, and show how to use these scalings as novel diagnostics of the underlying nonlinear plasma dynamics. These scalings, which we validate against results from high resolution particle-in-cell simulations using the LSP code[5], could find further use as essential "initial conditions" input into many petawatt laser models and applications.

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High-Z coatings for Hybrid Laser Indirect-Direct Drive*

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In our previous work with high-Z (Au and Pd) overcoats we found that above a threshold thickness (40 to 80 nm) they shield the underlying plastic target from direct illumination by the laser and produce an initial x-ray drive in simple direct-drive geometry. The x-ray driven ablation allows decoupling of the shorter spatial wavelength laser perturbations from the target, significantly reducing laser imprint in planar experiments on Nike[1]. Similar effects were subsequently observed in a series of joint LLE-NRL experiments on OMEGA[2]. Recent experiments[3] at NRL have extended the work on laser imprint suppression using thin coatings of high-Z metal to include the use of higher intensity laser spikes that are used in current direct drive implosion designs. We have also observed reduced amplitude of ablative Richtmyer-Meshkov oscillation for coated targets.[4]

For thin coatings, the initially x-ray drive switches to direct laser ablation when the coating density drops to well below critical density and the laser light penetrates it. Increasing the thickness of the coating delays this transition and leads to longer duration x-ray drive. The thicker coating would add the benefit of increased ablative stabilization of Raleigh-Taylor growth expected due to the high mass ablation rate with x-ray drive ,[5] presenting an attractive option for generating a hybrid indirect-direct drive configuration for improved drive uniformity without the complexities of a hohlraum. The talk will discuss our analysis of this configuration as well as recent and proposed experiments on Nike, Omega EP and the NIF.

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LEH Transmission and Early Fuel Heating for MagLIF with Z-Beamlet

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The Magnetized Liner Inertial Fusion (MagLIF) concept is designed to achieve high yield nuclear fusion by compressing a pre-magnetized, pre-heated fuel with a slow (v ~ 100 km/s) pulsed-power driven implosion[1]. To achieve fusion conditions with a slow implosion and modest convergence (~20), the MagLIF concept requires substantial pre-heat of the fuel as part of the pre-conditioning process of the target. At Sandia National Laboratories, this stage of the concept is achieved by using the Z-Beamlet laser, which can deliver multiple kilojoules to the target within several nanoseconds. The optimization of the MagLIF campaign requires improving the understanding and performance of the energy deposition of the laser into the fuel, which involves propagation through the Laser-Entrance-Hole (LEH) and coupling to the fuel behind the LEH window without introducing substantial contamination from window expansion or from fuel container ablation.

We present the results of several experimental campaigns with Z-Beamlet that were dedicated to the pre-heat aspect of MagLIF at Sandia's "Z" pulsed power facility and at the Pecos target chamber within Sandia's Z-Backlighter facility. We will discuss the relevance of the laser pulse properties such as pre-pulse or varying sized phase plates, and target variations. A wide range of diagnostics were applied and developed to record laser penetration including blast wave propagation from the leaser-heated region, backscattered laser light, LEH window destruction, and X-ray response of the window. Between the various diagnostics a set of data with spectral, spatial, and temporal resolution could be assembled. We will discuss the progress of the investigations and suggest further steps to fully understand the details of pre-heat for the MagLIF program at Sandia.

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The relationship between gas fill density and hohlraum drive performance at the National Ignition Facility

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NIF hohlraums with little to no gas fill (i.e. near vacuum hohlraums) have measured hohlraum x-ray drive and capsule stagnation times that are closely predicted with radiation hydrodynamic (RH) models[1]. In addition, these low gas-fill targets tend to show high laser coupling (> 95%) with minimal cross-beam energy transfer (CBET). However, without gas-fill there is hohlraum wall-motion, which may affect the motion of the laser spots and interfere with the inner beam propagation, impacting the symmetry of the implosion. Adding gas to the hohlraum, typically at densities on the order of ~1mg/cc, can help mitigate the problems associated with wall motion by holding back the ablated plasma. However, gas filled hohlraums have reduced coupling due to laser-plasma interactions (Stimulated Brillouin and Raman Scattering – SRS and SBS), require significant CBET to achieve implosion symmetry, and exhibit x-ray drive and stagnation times that are in disagreement with the RH simulations. The lack of predictability as gas density in the hohlraum increases suggests the onset of other processes that could act as sinks for laser energy, reducing the actual drive delivered to the capsule in ways that are not accounted for in the present models.

We have performed a series of NIF experiments in which the helium gas fill density was varied between 0.03 mg/cc and 1.6mg/cc in a 5.75mm hohlraum driven by a 2-shock pulse. The aim of these experiments is to characterize where the RH models are predictable and to provide insights into what physics might be responsible for the disparity between predicted and observed performance as gas density increases. Of particular interest were those observables directly related to hohlraum drive such as bang time and backscatter. Additionally, these experiments sought to investigate if, for this particular hohlraum and pulse, an intermediate gas fill could be utilized which maintained predictable hohlraum drive while producing symmetry in agreement with RH model predictions. We will present the results of the gas-fill scaling and describe how these results can guide us to optimize hohlraum performance while being predictable.

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Results from trailing-bunch acceleration in recent Plasma Wakefield Acceleration experiments at the FACET Facility at SLAC National Accelerator Laboratory

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A wakefield in a plasma encompasses the response of the ambient plasma to a disturbance traveling through the plasma. Much like a fast boat on a lake—where the bow displaces the water transversely only to come rushing back producing a wake behind the boat—the radial fields of an intense, relativistic electron drive-bunch will radially displace the plasma electrons until they come rushing back producing an enormous spike in the local electron density. The resulting wake, with $v_\phi = v_{drive}$, manifests as a localized spike of extremely high longitudinal electric field E_z which is very useful for accelerating a trailing bunch of electrons; the Plasma Wakefield Accelerator (PWFA) concept. For a drive bunch length $\sigma_z \sim \lambda_p/2$, this enormous E_z at the back of the wake drops to zero near the centroid of the drive bunch; i.e., a finite length (but low charge) trailing bunch may see a wide range of E_z leading to non-monoenergetic acceleration. Moreover, the radial oscillations of the plasma electrons can continue into a second, third, etc. "bucket" of an oscillating wake; e.g., the wake may be undamped leading to, by definition, very inefficient energy transfer from the drive bunch to the wake to the trailing bunch. This has been the salutation in LWFA experiments until recently; that is, the trailing electrons exited with a large energy spread and did not extract a significant fraction of the energy in the wake. Many applications of LWFA require just the opposite. The FACET experimental facility at SLAC was designed precisely to address these issues; producing a high-charge trailing bunch that cannot only extract significant energy from the wake's E_z field, but also perturb the wake itself to locally shape the E_z field to be ~ constant over the trailing bunch's longitudinal extent. This talk will report on such electron experiments as well as some exciting new results with positron-driven wakes.

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pF3D Simulations of Stimulated Brillouin Scattering in Rugby Hohlraums on NIF*

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Substantial stimulated Brillouin scattering (SBS) from the outermost (50 deg.) cone of laser beams occurred on a NIF experiment (shot N131011) with a rugby-shaped hohlraum and a low-adiabat ("low-foot") pulse shape[3]. The prior rugby experiment (shot N130502) had a different pointing of the outer beams and low cone-50 SBS. We present simulations results of outer-beam SBS on these targets, with the massively-parallel, paraxial envelope propagation code pF3D[1,2]. The runs simulate a full quadruplet ("quad") of 4 NIF laser beams, over the full propagation length from the laser entrance hole to the high-Z hohlraum wall (4.5 mm in the propagation direction, and 2.87 mm x 2.74 mm in the two transverse directions) for ~100 ps during the peak of the laser pulse. The real, speckled intensity pattern due to phase plates, smoothing by spectral dispersion (SSD), and polarization smoothing are all included. The runs utilized 262,144 cores of the IBM BlueGene/Q system Sequoia at LLNL, and comprised 200 billion spatial zones. The input plasma conditions were taken from radiation-hydrodynamic simulations run with the LASNEX code and the "high-flux model." No model of mix or species diffusion between the hohlraum wall and He fill gas was included, though these effects may be important for rugby targets. These simulations are the first in a series to explore the effect on SBS of quad pointing, beam pointing within a quad, and other mitigation techniques.

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Stimulated Raman Backscatter Trends from Gas Filled Hohlraum Experiments on the NIF

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The primary source of backscatter in experiments in gas filled hohlraums remains Stimulated Raman Scattering (SRS) from the inner cone quads. This SRS affects the x-ray, implosion symmetry, and can indirectly affect the implosion adiabat through the generation of hot electrons. Implosion core polar P2 symmetry is correlated with SRS levels measured on the inner cones during peak power. This is attributed to the SRS being a measure of the inner beam power after cross beam energy transfer (CBET) [1]. Since the National Ignition Campaign (NIC) ended, we have varied the gas fill, pulse shape, ablator and hohlraum geometry in attempts to improve implosion performance. In particular, some recent experiments aimed at mitigating the inner beam SRS increased the volume of the equatorial region where the exploding capsule ablator and hohlraum wall produce a channel of dense plasma. These experiments used larger cylindrical hohlraums and rugby hohlraums. We will present the SRS power and wavelength dependence of the SRS as a measure of the evolving hohlraum coronal plasma conditions.

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Modifying the Kinetic Behavior of Stimulated Raman Scattering with External Magnetic Fields*

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Several authors have recently hypothesized that external magnetic fields could constrain the detrimental impact of stimulated Raman scattering (SRS) on gas-filled hohlraums. Such fields could be used to raise the electron temperature, thereby increasing the damping rate of the daughter electron plasma wave (EPW)[1], and the fields will restrict the range of energetic electrons, thereby potentially changing the impact of preheat electrons[2] as well as limiting collective multi-speckle SRS[3]. An important, unexamined effect of external magnetic fields is their effect on resonant wave-particle interactions. Much theory and simulation over the last 15 years of SRS research has explored the impact of these interactions on the kinetic evolution of SRS. Here we show the effect of external magnetic fields on SRS in the kinetic regime for single- and multi-speckled lasers using two-dimensional particle-in-cell simulations. An external magnetic field collinear with the laser propagation direction acts to align trapped particles with the daughter electron plasma wave (EPW) in SRS, which, in addition to limiting collective speckle interactions, also makes two-dimensional SRS more 1D-like and enhances SRS growth. On the other hand, an external magnetic field perpendicular to the laser propagation direction acts to deflect trapped particles transversely across the daughter EPW and dynamically change the population of particles that are resonant with the EPW, disrupting the resonant wave-particle interactions and thereby their nonlinear effects on EPWs. This acts to decrease the SRS reflectivity and represents an additional mechanism by which external magnetic fields could be beneficial. Hot electron motion is restricted for either orientation, but to different effect with regard to SRS recurrence and speckle interactivity.

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