40th Annual

Anomalous Absorption Conference

Snowmass Village, Colorado • June 13-18, 2010

Organizing Committee

*Cedric Page * Thomas Kwan * Mark Schmitt * John Kline*

The University of New Mexico – Los Alamos

40th Annual

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s Village, Colorado • June 13-18, 2010

2008: LLE (Williamsburg)
2009: LLNL (Bodega Bay)
2010: LANL (Snowmass Village)
2011: UCLA (San Diego)
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2016: LLE (Old Saybrook)
2017: LLNL (Florence)
2018: NRL (Bar Harbor)
2019: LANL (Telluride)
2020/2021: NA (covid)
2022: LLE (Skytop)
2023: Mammoth Lakes, CA
2024: Big Sky, MT

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All conference locations

1971 -- Princeton, NJ
1972 -- Boulder, CO
1973 -- Los Alamos, NM
1974 -- Livermore, CA
1975 -- Los Angeles, CA
1976 -- Vancouver, BC
1977 -- Ann Arbor, MI
1978 -- Tucson, AZ
1979 -- Rochester, NY
1980 -- San Francisco, CA
1981 -- Montreal, Canada
1982 -- Santa Fe, NM
1983 -- Banff, Alberta, Canada
1984 -- Charlottesville, VA
1985 -- Banff, Alberta, Canada
1986 -- Lake Luzerne, NY
1987 -- Tahoe City, CA
1988 -- L'Esterel, Quebec, Canada
1989 -- Durango, CO
1990 -- Traverse City, MI
1991 -- Banff, Alberta, Canada
1992 -- Lake Placid, NY
1993 -- Wintergreen, VA
1994 -- Monterey, CA Pacific Grove
1995 -- Aspen, CO
1996 -- Fairbanks, AK
1997 -- Vancouver, BC, Canada
1998 -- Bar Harbor, ME
1999 -- Monterey, CA
2000 -- Ocean City, MD
2001 -- Sedona, AZ
2002 -- Oahu, HI
2003 -- Lake Placid, NY
2004 -- Gleneden Beach, OR ←
2005 -- Fajardo, Puerto Rico ← Glowing w
2006 -- Jackson Hole, WY ← Yellowstone visit
2007 -- Maui, HI ← Luau
2008 -- Williamsburg, VA
2009 -- Bodega Bay, CA
2010 -- Snowmass, CO

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The 40th Annual Anomalous Absorption Conference Agenda
June 13-18th, 2010

Sunday, June 13

6:30pm-8:30pm		Silvertree Reception	Conservatory (Main Lobby)

Monday, June 14

7:00-8:15 am		Breakfast		Eldorado Rm
8:00am-8:15am		Welcome Introduction/Logistics	Cedric Page (UNMLA) Tom Kwan (LANL)	Cabaret Room

Laser Plasma Interaction (I)		**Session Chair D. Montgomery (LANL) Cabaret Room**
8:15-8:55 am (Invited)	D. A. Callahan (LLNL)	Optimizing the Ignition Hohlraum based on the 2009 NIC Energetics Campaign
8:55-9:15 am	N. B. Meezan	Energy Balance in National Ignition Campaign Hohlraums
9:15- 9:35 am	D. E. Hinkel	Stimulated Raman scatter analyses of the Energetics Campaign conducted at the National Ignition Facility
9:35-9:55 am	G. A. Kyrala	Anomalous Bright Spot Emission in Symcap Implosions at the NIF
9:55-10:15 am	R. K. Kirkwood	Multi-Beam Effects on Scattered Light Under Ignition Conditions
10:15-10:30 am		Break

Laser Plasma Interactions (II)		**Session Chair: R. Kirkwood (LLNL) Cabaret Room**
10:30-10:50 am	E. A. Williams	SRS backscatter analyses of NIF energetic Campaign Experiments using SLIP
10:50-11:10 am	B. B. Afeyan	Spike Trains of Uneven Duration and Delay: STUD Pulses for the Effective Control of Laser Plasma Instabilities for Direct and Indirect Drive and Shock and Fast Ignition
11:10-11:30 am	C. Rousseaux	Development of laser plasma instabilities during the interaction of two successive ps pulses at moderate intensity: space-and time-resolved Thomson scattering measurements
11:30-11:50 am	R. L. Berger	The dependence of Stimulated Brillouin Scattering of the inner NIF beams on hohlraum fill gas pressures
11:50-12:10 pm	J. D. Moody	Inferring SRS growth behavior from the time-dependent backscatter in NIF hohlraums
12:10 pm		**Lunch** **Eldorado Rm**

Laser Plasma Interaction (III)	Session Chair:	M. Schmitt (LANL)	Cabaret Room
7:30-8:30 pm (Plenary)	A. Schmitt (NRL)	Designing shock ignition targets	

8:30-10:30 pm	Poster Session I (LPI)	Kearns Room

1	M. Cassanova	Frequency and damping of ion-acoustic waves in multi-species plasmas. New results.
2	S. M. Finnegan	Modeling short-pulse single hot-spot laser plasma interaction experiments using the VPIC particle-in-cell code
3	L. Yin	Backwards stimulated Raman and Brillouin scattering of laser in the trapping regime: Effects of collisions and seed amplitude
4	T. Grismayer	Revising Landau damping for finite plasma parameters
5	D. Montgomery	Nonlinear Optics of Plasmas: Exciting Research Prospects in High Energy Density Laboratory Plasmas
6	B. B. Afeyan	Two Plasmon Decay in Transversely Localized Laser Hot Spots From Theory to Direct Thomson Scattering Measurements and 3/2 Harmonics Signature on Trident for Direct Drive and Shock Ignition
7	W. Kruer	Laser plasma physics important for NIF hohlraums
8	R. Yan	Saturation, laser absorption and hot electron generation in two-plasmon decay instabilities in inertial confinement fusion
9	B. Winjum	Particle-in-cell Simulations of Stimulated Raman Re-scattering
10	F. Tsung	The Nature of Absolutely and Convectively Unstable Modes Near the Quarter Critical Surface of Inertial Fusion Energy Targets
11	C.H. Still	Multibeam SRS modeling with pF3d*
12	L. Divol	Hot electron measurements and Stimulated Raman Backscatter on NIF
13	J. Cooley	Examination of Sensitivities for Strong Shocks in Cassio
14	J. Fahlen	Nonlinear, Local Kinetic Damping of Finite-Width Plasma Waves Relevant to Stimulated Raman Scattering
15	S. H. Glenzer	Mega-joule experiments on the National Ignition Facility-on the road to produce a microscopic star in the laboratory
16	D. H. Edgell	Anisotropic distribution of hard x-rays from the two-plasmon-decay hot-electron distribution
17	J. Tonge	Anomalous stopping due to macro-particles in PIC simulations
18	J. A. Hittinger	Beyond 1D: Algorithmic Advances for More Tractable Vlasov Simulation
19	I. N. Ellis	The Onset of Inflation and the Effects of Seed Pulses on SRS and Molecular Dynamic Studies of Particle Wake in Plasmas
20	M. Porkolab	Studies of Waves and Turbulence in Tokamak Plasmas with Phase Contrast Imaging and Comparisons with Code Predictions by Synthetic Diagnostics

Tuesday, June 15

7:00-8:15 am		Breakfast	Eldorado Rm
Radiation Hydrodynamics Session		**Session Chair N. Meezan (LLNL)**	**Cabaret Room**
8:15-8:55 am (Invited)	T. Collins (LLE)	Preparing for polar drive at the National Ignition Facility	
8:55-9:15 am	S. V. Weber	Modeling of Capsule Data from the First NIF Experiments	
9:15- 9:35 am	R. E. Olson	X-Ray Conversion Efficiency in NIF Vacuum Hohlraum Experiments	
9:35-9:55 am	P. A. Amendt	The potential role of plasma barotropic diffusion on ICF implosion performance with thermonuclear fuel mixtures	
9:55-10:15 am	C. K. Li	Observations of Spontaneous Electromagnetic Fields, Plasma Flows, and Implosion Dynamics in Indirect-Drive Inertial-Confinement Fusion	
10:15-10:30 am		Break	
Radiation Hydrodynamics Session		**Session Chair: P. Amendt (LLNL)**	**Cabaret Room**
10:30-10:50 am	O. S. Jones	Capsule Performance in Presence of Surface Perturbations and Drive Asymmetry	
10:50-11:10 am	S. X. Hu	Two -dimensional radiation-hydrodynamic simulations of cryogenic-DT implosions at the Omega Laser Facility	
11:10-11:30 am	R. A. London	Non-local electron transport in hohlraums at the National Ignition Facility	
11:30-11:50 am	P. Bonoli	Integration Issues for Simulating Wave-Particle Interactions in Tokamak Plasmas*	
11:50-12:10 pm	R. Harvey	The Fokker-Planck Equation as Applied to RF Physics in Magnetic Fusion Energy Research	
12:10 pm		Lunch	**Eldorado Room**

EOS and FI	**Session chair**	**T. Kwan (LANL)**	**Cabaret Room**
7:30-8:30 pm (Plenary)	L. Yin (LANL)	Three-dimensional dynamics of break-out afterburner ion acceleration using high-contrast short-pulse laser and nano-scale targets	

8:30-10:30 pm	**Poster Session II (EOS and FI)**	**Kearns Room**

1	J. A. Cobble	TPIE: Thomson Parabola Ion Energy Analyzer
2	M. G. Haines	Electrothermally generated filaments in laser-solid interactions

3	J.C. Wright	Challenges in self-consistent full wave simulations
4	T. M. Austin	A low-noise δf particle-in-cell method for simulating ICRF Physics
5	A. Kemp	Picosecond scale iteration of energetic ultra-intense laser pulses with plasma gradients
6	J. May	Electron Acceleration by High Intensity Lasers at Sharp Matter Interfaces
7	D.W. Schumacher	LSP modeling of the LPI and the resulting hot electron divergence and K emission in slabs and buried cones
8	B. G. Wilson	Multi-Center Electronic Structure Calculations For Plasma Equation of State
9	C. Starrett	An average atom model with electronic bands
10	Z. Zhao	Subwavelength nanobrush target to efficiently accelerate and collimate fast electrons
11	R. Shepherd	Proton energy loss measurements in high density, low temperature plasma
12	H.Wu	Laser-like x-ray sources based on optical reflection from relativistic electron mirror
13	C. K. Huang	Improving beam spectral and spatial quality by double-foil target in laser ion acceleration
14	H. Shiraga	Integrated experiments of Fast Ignition with Gekko-XII and LFEX lasers
15	F. Fiuza	Efficient one-to-one modeling of inhomogeneous plasmas
16	E. Liang	Production and Applications of Dense Laser Pair Plasmas
17	J. O. Kane	Multi-keV X-ray Yields from High-Z Gas Targets Fielded at the OMEGA Laser the National Ignition Facility
18	S. Hamel	Transport properties of Low-Z mixtures
19	F. Graziani	Kinetic Theory Molecular Dynamics

Wednesday, June 16

7:00-8:15 am		Breakfast	Eldorado Rm

Fast Ignition (I)	**Session Chair: B. Albright (LANL)**	**Cabaret Room**
8:15-8:55 am (Invited)	K. Shigemori (ILE)	Earth and planetary science study with Gekko-XII-HIPER laser facility at ILE, Osaka University
8:55-9:15 am	Y. Gu	Fast Ignition Research at LFRC
9:15- 9:35 am	J. C. Fernandez	Fast Ignition with Laser-Driven Ion Beams
9:35-9:55 am	R. Trines	Simulations of efficient Raman amplification into the Petawatt regime
9:55-10:15 am	P. Michel	Towards a better understanding of Laser Plasma Interaction on the National Ignition Campaign
10:15-10:30 am		Break

Fast Ignition (II)	**Session Chair: J. Fernandez (LANL)**	**Cabaret Room**
10:30-10:50 am	S. R. Nagel	Control of Relativistic Electron Generation on High-Intensity Laser-Solid Interactions
10:50-11:10 am	D. J. Strozzi	Modeling of Electron-Driven Fast Ignition at Ignition Scale
11:10-11:30 am	D. Ho	Indirect-Drive Fast-Ignition Capsule Designs
11:30-11:50 am	C. Ren	Laser Channeling and Hosing in Millimeter-Scale Underdense Plasmas for Fast Ignition
11:50-12:10 pm	J. O. Kane	Modeling of the LIFE minichamber Xe theta pinch experiment
12:10 pm		Lunch **Eldorado Room**

Banquet:

6:00-7:00 pm	Gondola up to AMC and cocktail reception		Aspen Mtn Club
7:00-8:30pm	Banquet Dinner		
8:30-9:15pm	Historical talks/comments	T. Kwan (LANL)	Kruer/Dubois/Porkolab
9:15pm	Gondola down to Aspen		

Thursday, June 17

7:00-8:15 am		Breakfast	Eldorado Rm
Modeling	**Session Chair:**	**J. Tonge (UCLA)**	**Cabaret Room**
8:15-8:55 am (Invited)	P. Loiseau (CEA/DAM)	Ignition design for the laser megajoule (LMJ) and laser-plasma instabilities mitigation	
8:55-9:15 am	J. A. Hittinger	Two- dimensional Vlasov Simulation of Driven, Nonlinear Electron Plasma Waves	
9:15- 9:35 am	R. Kirkpatrick	e-PLAS electron transport modeling for laser-driven fusion	
9:35-9:55 am	A. Link	LSP modeling of the modification of escaping energetic electron spectra	
9:55-10:15 am	A. B. Sefkow	Predictive capability for Z-Petawatt-driven high-energy K x-ray yields used to image HEDP experiments on the Z machine	
10:15-10:30 am		Break	
EOS/WDM	**Session Chair**	**M. Desjarlais (SNL)**	**Cabaret Room**
10:30-10:50 am	F. Graziani	Molecular Dynamics of Hot Dense Matter	
10:50-11:10 am	M. Desjarlais	XUV opacity of warm dense aluminum	
11:10-11:30 am	C. Fortmann	Dynamical structure factor for dense plasmas: Extended Born-Mermin theory and application to x-ray scattering for dense plasma diagnostics	
11:30-11:50 am	J. Kress	Mixtures in the Warm, Dense Matter Regime	
11:50-12:10 pm	G. Collins	Recreating Core States of Giant Planets, a new generation of condensed matter science	
12:10 pm	**Lunch**		**Eldorado Room**
7:00-7:30 pm	**Business Meeting**	**J. Kline (LANL)**	**Cabaret Room**
Rad-Hydro Session	**Session Chair**	**J. Kline (LANL)**	**Cabaret Room**
7:30-8:30 pm (Plenary)	B. Hammel (LLNL)	Controlling and Diagnosing Hot-Spot Mix in NIF Implosion Experiments	
8:30-10:30 pm	**Poster Session III (Rad-hydro)**		**Kearns Room**

1	B. B. Afeyan	Quantitative Analysis of Structured Implosions a Combination of Different Wavelets, Curvelets and Geometric Measure Theory: From Target Surface Imperfections to Hydrodynamic Instabilities and Mix

2	K. A. Defriend Obrey	ICF Targets: Defect implosion experiments on Omega and NIF and characterization of copper doped beryllium capsules
3	P. A. Bradley	Investigations of Mix in Omega and NIF Capsules with an Eulerian Code
4	S. M. Finnegan	Modeling direct-drive implosions using HYDRA
5	M. V. Patel	Applications of the HYDRA Detailed Configuration Accounting (DCA) Package
6	S. Langer	Comparisons of simulated x-ray data to NIF experiments
7	E. Loomis	Experiments to Measure Ablative Richtmyer-Meshkov Growth of Gaussian Bumps in Plastic Capsules
8	I. Tregillis	Optimizing Direct-Drive Performance for Thin-Shell ICF Implosions on NIF
9	G. R. Magelssen	Technique for measuring the zero-order hydrodynamics of a directly laser driven imploding thin-shelled capsule
10	K. J. Peterson	The Effects of Radiation Transport on the Development of Instabilities in NIF capsules
11	N. M. Hoffman	Gamma rays and the areal density of ICF capsules: Beyond the MIPS Model
12	S. Hsu	Multiple Monochromatic Imager and Phase Contrast Imaging Diagnostics for Thin Shell Implosions on NIF
13	J. G. Wohlbier	Progress Towards a Radiation Hydrodynamics Code for Modern Computing Architectures
14	E. S. Dodd	The effect of mix on symmetry capsule performance at the NIF
15	L. Yu	Generation of tens of GeV quasi-monoenergetic proton bunches with lasers at intensity 10^{21}~10^{23} W/cm^2
16	J. L. Kline	Investigation of electron heat conduction in Laser Produced Exponential Plasma Density Profiles
17	I.N. Ellis	Molecular Dynamic Studies of Particle Wake Potentials in Plasmas
18	A.B. Langdon	Theory of superhot electron spectra generated by Raman scatter

Friday, June 18

7:00-8:15 am		Breakfast	Eldorado Rm
Laser Plasma Interaction (III)		**Session Chair: W. Kruer (LLNL)**	**Cabaret Room**
8:15-8:55 am (Invited)	K. Flippo (LANL)	Laser-Based Ion Beam Development for Dynamic Defects and Fast Ignition Fusion	
8:55-9:15 am	S. Finnegan	Influence of binary Coulomb collisions on trapped particle nonlinearities related to the onset of stimulated Raman backscatter in the kinetic regime	
9:15- 9:35 am	J. L. Martins	Radiation signatures of electromagnetic plasma microinstabilities with relativistic beams	
9:35-9:55 am	D. Jung	New ion acceleration mechanisms in relativistic laser nanotarget interactions	
9:55-10:15 am	W. Seka	SBS, SRS, and TPD in planar target experiments relevant to direct-drive ICF	
10:15-10:30 am		Break	
Laser Plasma Interaction Session		**Session Chair: A. Schmitt (NRL)**	**Cabaret Room**
10:30-10:50 am	J. Myatt	Calculations of preheat caused by the two-plasmon-decay instability in direct-drive ICF plasmas	
10:50-11:10 am	H. Vu	Hot-electron generation by the two-plasmon-decay instability in inhomogeneous plasma	
11:10-11:30 am	A. Maximov	Modeling of two-plasmon-decay-instability in the plasmas of direct-drive inertial confinement fusion	
11:30-11:50 am	R. Short	Anisotropy of collectively driven two-plasmon decay in direct-drive spherical irradiation geometry	
11:50-12:10 pm	Z. Sheng	On some nonlinear effects in laser absorption in plasmas	
12:10 pm		Conference adjourns	

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Monday, June 14, 2010

Laser Plasma Interaction (I)

Session Chair: D. Montgomery, LANL

D. A. Callahan. LLNL (Invited)

N. B. Meezan, LLNL

D. E. Hinkel, LLNL

G. A. Kyrala, LANL

R. K. Kirkwood, LLNL

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Optimizing the Ignition Hohlraum based on the 2009 NIC Energetics Campaign*

D. Callahan, N. Meezan, S. Glenzer, P. Michel, L. Suter, D. Bradley, E. Dewald, L. Divol, E. Dzenitis, S. Dixit, M. Edwards, S. Haan A. Hamza, C. Haynam, D. Hinkel, O. Jones, D. Kalantar, J. Kilkenney, J. Kline†, G. Kyrala†, O. Landen, J. Lindl, B. MacGowan, J Milovich, J. Moody, A. Nikroo‡, T. Parham, M. Rosen, M. Schneider, R. Town, P. Wegner, K. Widmann, P. Whitman, B. Young, B. VanWontergham, L. Atherton, E. Moses
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†Los Alamos National Laboratory, Los Alamos, NM
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The first target physics campaign on NIF was designed to experimentally test the energetics and symmetry control of the ignition point design hohlraum. Based on the campaign of ~ 30 shots, we believe that we have a hohlraum that provides the drive and symmetry control needed to move forward towards ignition. Over the course of the campaign, we varied several of the parameters available to us: hohlraum materials, wavelength separation between inner and outer cones, laser intensity (by using small phase plates to reduce the spot size), and hohlraum gas-fill density. We explored laser pulses that are appropriate for both plastic (CH) and beryllium ablators. These experiments used cryogenic hohlraums with "symmetry capsules," which are gas-filled surrogates for the layered targets used for ignition; they provide the same hohlraum environment as the ignition capsule and allow us to measure the shape of the hotspot at peak compression, but at lower convergence ratio and without the complication of layered targets. For these shots, we measured the hohlraum radiation drive using the Dante drive diagnostic, the backscattered light using FABS and NBI, size of the LEH by the SXI,.hot electrons with the FFLEX, and symmetry of the imploded capsule with the GXD. As a result of the campaign, we have made several changes to the point design hohlraum: hohlraum gas-fill is now pure helium, hohlraum wall liner is now pure gold, and the wavelength separation between the inner and outer cones is larger than previous designs. The campaign culminated with a shot at ignition-scale using 1 MJ of laser energy; based on this experiment, we believe that we can reach the required 300 eV for the CH point design with ~1.3 MJ of laser energy. This talk will discuss the experiments and the basis for these changes in the point design hohlraum.

[1] S. H. Glenzer, et. Al., *Science*, **327**, 1228 (2010).
[2] N. B. Meezan, et. Al, *Phys of Plasmas*, **17**, 056304, (2010).
[3] P. Michel, et. Al, *Phys of Plasmas*, **17**, 056305, (2010).
*This work was performed under the auspices of the U.S. DOE by Lawrence Livermore National Lab under contract DE-AC52-07NA27344 and by Los Alamos National Laboratory under contract DE-AC52-06NA25396.

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Energy Balance in National Ignition Campaign Hohlraums*

N. B. Meezan, R. P. J. Town, D. A. Callahan, R. A. London, J. L. Milovich, E. L. Dewald, L. Divol, S. N. Dixit, C. A. Haynam, D. E. Hinkel, O. S. Jones, J. L. Kline[†], G. A. Kyrala[†], O. Landen, P. Michel, J. D. Moody, R. E. Olson[‡], M. D. Rosen, M. B. Schneider, C. A. Thomas, M. J. Edwards, S. H. Glenzer, L. J. Suter, and B. J. MacGowan,
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[‡]Sandia National Laboratory, Albuquerque, NM

This talk presents recent progress in analyzing and modeling the 2009 National Ignition Campaign Hohlraum Energetics experiments. Two primary goals of the experiments were to measure the amount of laser energy absorbed by the hohlraum and to measure the intensity of emitted x-rays. Vacuum hohlraum experiments early in the campaign clearly showed x-ray conversion efficiencies higher than those predicted by the radiation-hydrodynamics codes LASNEX and HYDRA using standard models. In gas-filled hohlraums, Stimulated Raman Backscatter (SRS) spectral data suggested lower electron density and/or lower electron temperature than predicted by the codes. New simulations with higher x-ray emissivity atomic models and increased electron thermal conductivity are in better agreement with these data. These simulations also include revised laser power data and SRS backscatter data that reduce the net laser energy absorbed by the hohlraum. We assess the validity of the new models by comparing post-shot simulations to hohlraum performance data. Discrepancies between predicted and measured x-ray radiant intensity (GW/sr as measured by the DANTE diagnostic) are expressed in terms of equivalent laser energy.

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

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Stimulated Raman scatter analyses of the Energetics Campaign conducted at the National Ignition Facility*

D. E. Hinkel, M. D. Rosen, E. A. Williams, R. P. J. Town, R. A. London, D. A. Callahan, C. H. Still, A. B. Langdon, P. A. Michel, and S. H. Langer
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The recent energetics campaign[1] conducted at the National Ignition Facility in Fall, 2009 achieved its two main goals: providing the radiation drive and symmetry necessary for the first credible attempt at ignition. Many diagnostics were fielded during this campaign, one of which provided a time-resolved wavelength spectrum of light reflected from the target by stimulated Raman scatter (SRS). SRS occurs when incident light reflects off self-generated electron plasma waves.

The SRS spectrum of an inner cone (30°) quad has provided key insight into these experiments. Analyses indicate that synthetic SRS diagnostics of radiation-hydrodynamic simulations better match those of experiments when an atomic physics model with greater emissivity is utilized, along with less inhibited electron transport (higher flux model, or, ideally, nonlocal electron transport). In these new rad-hydro simulations, SRS primarily occurs in a region of the target where nearest-neighbor 23° quads significantly overlap the diagnosed 30° quad. This increases the gain at lower density (lower wavelength), a feature consistent with the experimental results.

Inclusion of the effect of multiple beams sharing a reflected SRS light wave has resulted in modifications to both LIP, our post-processor to rad-hydro simulations, and to pF3D, our beam propagation code[2]. We present here a comparison of our LIP results to experiments, and preliminary results from propagating multiple beams in pF3D.

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

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[1] N. B. Meezan *et al.*, Phys. Plasmas **17**, 056304 (2010).

[2] C. H. Still, this conference.

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Anomalous Bright Spot Emission In Symcap Implosions at NIF *

Presentor: G. A. Kyrala, J. Koch[†], P. Springer[†], M. J. Edwards[†], S. V. Weber[†], S. Haan[†], N. Izumi[†]
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We have observed bright spots in the x-ray emission from implosions of CH symcaps driven by hohlraum radiation at NIF. We have observed these bright spots from two orthogonal directions, along a hohlraum axis, as well as normal to the hohlraum axis through a diagnostics hole. In this work we will show a summary of the observations from these directions, describe some of the issues that arose, describe some of the properties of the bright spots, show how their number depends on different parameters, or how some of the measured parameters depend on their number, how their presence affects the symmetry measurement of the implosion, and finally describe their motion in three dimensions.

* This work was performed by Los Alamos National Laboratory under the auspices of the U. S. Department of Energy under contract No. DE-AC52-06NA25396.

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Multi-Beam Effects on Scattered Light Under Ignition Conditions*

Presenter R. K. Kirkwood, Y. Ping, T.L. Wang†, Lin Yin††, P. Michel, R. London, D. Callahan, N. Meezan, E. Williams, C. Joshi†, S. Glenzer, L. Suter, O. Landen
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Stimulated scattering of both SRS and SBS light produced by a single beam interacting in a hohlraum can be enhanced by re-amplification by the multiple crossing beams it encounters as it exits the target [1]. Analysis of this effect in ignition targets has motivated experiments on smaller lasers and simulations modeling these effects. This paper considers the effect of multi-beam interactions on the backscatter in ignition hohlraums and will look beyond the well recognized effects of energy and power transfer between forward propagating beams [2,3] to discuss research on similar effects that allow multiple crossing beams to collectively re-amplify backscatter [4,5] even in the presence of wave non-linearity. Jupiter experiments with a seed beam and a single crossing pump beam have tested the linearity of the response of the Langmuir waves that re-amplify SRS. 1D and 2D PIC simulations will be compared with the Jupiter experiments and shown to model the non-linear electron wave response well. We will further describe on-going Omega experiments that, for the first time have demonstrated cumulative amplification of a seed beam of light by the ion acoustic waves driven by multiple crossing beams. Initial results indicate that the ion wave energy amplification factor produced by a single pump is squared when a second pump is added with the same crossing angle relative to the seed beam, as expected.

[1] P. Michel et al., at this conference.
[2] P. Michel et al., Physics of Plasmas **17**, 056305 (2010)
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40th Annual

Anomalous Absorption Conference

Snowmass Village, Colorado • June 13-18, 2010

Monday, June 14, 2010

Laser Plasma Interaction (II)

Session Chair: R Kirkwood, LLNL

E.A. Williams, LLNL
B.B. Afeyan, Polymath Research, Inc.
C. Rousseaux, CEA/DAM
R.L. Berger, LLNL
J.D. Moody, LLNL

UNM LOS ALAMOS

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SRS backscatter analyses of NIF Energetics Campaign Experiments using SLIP*

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SLIP is a code, based on pF3D, that solves steady state coupled paraxial wave equations on a given underdense plasma background. The coupling between the light waves is given by the steady-state (strong damping) kinetic response of the background plasma to the ponderomotive beat force.

As a model, and in computer resources, SLIP lies between LIP and pF3D. LIP integrates the kinetic coupling coefficients along laser rays, and is thus blind to the effects of speckles and diffraction, and offers difficulties of interpretation when there is a wide distribution of gains among the rays. pF3D, on the other hand, evolves the waves, the plasma response and the background plasma in time and thus can naturally account for the effects of SSD, filamentation, plasma evolution and finite backscatter bandwidth, which steady-state calculations cannot However, pF3d simulations on the NIF ignition scale require very significant computing resources.

Here we present two applications of SLIP to the analysis of SRS backscatter data from experiments performed in the recent NIF Energetics Campaign.

First, we believe that the SRS backscatter observed in the 30 degree FABS and NBI diagnostics originates in a region where the 30 degree beam overlaps with its 23 degree nearest neighbors and that those overlapping beams may contribute to the amplification of the backscatter. pF3D simulations of the entire beam paths are not currently feasible, but one including only the SRS interaction volume is. SLIP is used to propagate the beams, accounting for refraction, absorption and crossed-beam transfer to the input plane of the pF3d simulation.

Second, using SLIP in its back-and forth, pump propagation and SRS backscatter amplification mode, we can properly account for refraction of the SRS as it exits the hohlraum. We create synthetic images of the SRS spatial distribution at the FABS and NBI diagnostics as a function of time within the laser pulse, to compare with the experimental data. This will test our understanding of the plasma conditions in the hohlraum.

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Spike Trains of Uneven Duration and Delay: STUD Pulses for the Effective Control of Laser Plasma Instabilities for Direct and Indirect Drive and Shock and Fast Ignition

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The recently proposed scheme of composing the laser pulse out of a series of parametric instability growth-time-scale spikes and similar time scale off sections in order to avoid cumulative growth of such instabilities, called STUD pulses, will be exposed. As a specific example, the weak and strong damping limits of Stimulated Brillouin Scattering (SBS) will be treated in RPP, SSD, pseudo-STUD and STUD pulses and nonuniform flowing plasmas. The RPP pattern changes from "on" spike to spike in the STUD pulse case, but does not in the pseudo-case, while the effects of damping between spikes is a shared feature of both. The RPP pattern moves sideways slowly in the SSD case and does not change at all for a frozen RPP profile. Comparison of these cases will reveal the correct design principles with which to construct STUD pulses to match the local changing plasma conditions and keep all parametric instabilities under control.

On the theoretical side, we will show how Adler's techniques for Gaussian Random Fields, as generalized by Garnier (1999, 2001) for complex fields, can be used to estimate the asymptotic behavior of parametric instability growth for hot spots with mean intensities larger than 2.5 to 3 times the average intensity. We will also show how to treat the most intense hot spots beyond the mean "density of states" level using techniques also developed by Garnier (1999) and extended recently by Huller (2010).

Further estimates will be presented on the spatial recurrence time of hot spots using the theory of Gaussian Random Fields. The advantage of STUD pulses over SSD and ISI will thus be explicitly quantified. These differences come to the fore most strikingly in conditions of crossing or overlapping laser beams which are ubiquitous in ICF and IFE. Here STUD pulses allow the strict control of LPI by allowing beams to overlap or not to overlap in time, even if they are overlapped in space. This has strong implications for direct drive and shock ignition as well as fast ignition.

For indirect drive, STUD pulses allow the return to Green light (second as opposed to third harmonic in glass lasers), the use of higher pressure drives, and thus the possibility of deploying thicker ablators, which would alleviate the danger of interrupted burn propagation due to strong mixing driven by hydrodynamic instabilities at the fuel-ablator interface (a suggestion made by Mark Herrmann of Sandia). Disallowing cross talk between different regions of large hohlraum plasma by disallowing the reamplification of each other's unstable waves is yet another attractive feature of STUD pulses absent from current laser illumination methods.

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Development of laser plasma instabilities during the interaction of two successive ps pulses at moderate intensity: space- and time-resolved Thomson scattering measurements

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The development and saturation mechanisms of the electron plasma waves (EPW) and ion acoustic waves (IAW) respectively driven by stimulated Raman (SRS) and Brillouin (SBS) backscattering are experimentally investigated using the LULI 100-TW laser facility. In this experiment, the laser parametric instabilities (LPI) are excited by two successive 1ω, 1.5 ps laser pulses, separated by 3 or 6 ps. The pulses are fired at f/17 into a pre-ionized He plasma ($n_e \sim 5\text{-}7x10^{19}$ cm^{-3}). Our objective is to investigate the potential coupling between the instabilities driven by the two pulses as a function of the system parameters. The shots are analyzed through two simultaneously operated, time-resolved ($\tau = 300$ fs), Thomson-scattering diagnostics. The first one measures the driven IAW and EPW spectra along the laser pump direction (z axis). The second one provides space-resolved measurements of the spectra along the direction perpendicular to the pump direction simultaneously at two or three z locations. The time delay between the two pulses, the initial gas pressure and the intensity of the first pulse have been varied. Due to the moderate fixed intensity ($I_{max} = 2x10^{16}$ W/cm^2) of the second pulse, the detected IAWs may not necessarily result from SBS. Second pulse–driven recovery of SRS is observed at low electron density with 3 ps time delay or with 6 ps time delay at higher electron density. As SRS saturates, the EPW spectra exhibit a surprisingly large radial extension around the interaction volume, together with a significant frequency downshift of the EPWs which is found to decrease with the radial distance [1] [2]. The potential implications of the experimental measurements will be briefly discussed.

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The dependence of Stimulated Brillouin Scattering of the inner NIF beams on hohlraum fill gas pressures*

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Stimulated Raman and Brillouin backscatter from gas-filled hohlraums have been measured from two quads of laser beams at the National Ignition facility in 2009. The time history and the spatial distribution in the near field are measured for the outer beams at 50° and the inner beams at 30° to the hohlraum axis. The SRS and SBS of the inner beams show an interesting dependence on the fill gas pressure. For the nominal hohlraum gas fill pressure of 420 torr helium at 20K, SRS is typically measured during the high power part of the laser pulse at levels of 10-20% of the incident beam energy. Less than 1% SBS is measured. For a few targets where the fill pressure was 210 torr or less, the SBS for these inner beams rises to greater than 10% without a significant decrease in SRS. The total backscatter from the outer beams is measured to be small at all times for all hohlraum gas fill pressures
Using the plasma parameters from hydrodynamic simulations that match the radiation temperature and capsule symmetry, we find the simulated SBS and SRS spectra and compare them to the measured spectral histories. The appearance of SBS at low fill pressure is simulated with 3d pF3D simulations.

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Inferring SRS character from time-dependent measurements of backscatter in NIF hohlraums

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SRS backscatter light from NIF hohlraum experiments is measured using a full aperture backscatter system (FABS) and a near backscatter imager (NBI). We have added time-dependent measurements to the NBI for the first time. This capability allows us to achieve ≤ 20% error on the backscatter power and to create a movie of the time history of the 2-D backscatter light distribution from the target with ~ 0.2 ns time resolution. We also observe a 3 GHz amplitude modulation in the SRS measurements correlated with small power modulations in the pump laser (due to SSD). These measurements provide a way to experimentally investigate the linearization of the SRS around the average pump intensity and infer SRS growth properties. We estimate the SRS gain and infer partly to significantly saturated SRS. We will describe the time-dependent backscatter measurements, show analysis of the results, and compare with modeling.

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Plenary I

Session Chair: M. Schmitt, LANL

A. Schmitt, NRL

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Designing shock ignition targets*

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The design and optimization of shock ignition[1] targets is discussed, Like fast ignition, the separation of the drive pulse into a compression and an igniting parts in shock ignition offers more flexibility and possibilities for producing high gains at reduced drive energy. The reduced implosion velocity requirements, low target adiabats, and efficient drive by short wavelength lasers allow these targets to produce gains over 100 at laser energies well below one megajoule[2]. Additionally, the effects of hydrodynamic instabilities like Rayleigh-Taylor or Richtmyer-Meshkov can be greatly reduced by using low-aspect ratio targets enabled by the low implosion velocities. Of particular interest in these two-part ignition scenarios is the optimum division of the pulse energy into ignitor to compression pulses. A simple pellet model and simulation-derived coupling coefficients are used to predict and analyze optimal fuel assembly. We determine that shock ignition allows enough control to create theoretically optimum assemblies. The effects on target design due to constraints on the compression and ignitor pulse intensities are also considered and addressed. Finally, significant sensitivity is observed from low-mode perturbations in these large convergence ratio implosions, but this can be remedied with a more powerful ignitor.

*This work supported by U.S. Office of Naval Research and U.S. Department of Energy.

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Poster Session I
LPI

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Frequency and damping of ion-acoustic waves in multi-species plasmas. New results.

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In laser-plasma interaction studies, parametric instabilities are one of the main concerns. The level of these instabilities is very dependent on the frequency and damping of the waves which are involved in the coupling process. A good knowledge of these parameters is thus essential to control these instabilities. Furthermore, it is well known that the superposition principle does not apply in mixtures. More specifically, several studies on ion acoustic waves have shown[1,2,3,4] that resonances do appear when the ionic composition or the electron to ion temperature ratio vary. These resonances can be used favorably to reduce the instability levels. We have studied several ionic mixtures. We will show new results and analytical fits which are to be implemented in our interaction codes. This will be done in order to improve the modeling of ion acoustic waves in mixtures while preserving a highly efficient computation performance. The error made by using mono-species[5] calculus and the superposition principle will be assessed.

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Modeling short-pulse single hot-spot laser plasma interaction experiments using the VPIC particle-in-cell code*

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1D and 2D VPIC[1] simulations of short-pulse (~3 ps FWHM) single hot-spot laser plasma interaction experiments[2] at the Trident laser facility are presented and compared with experimental observations. Recently, a numerical particle-pairing collision algorithm[3], which models a collision integral of the Landau form, has been implemented within VPIC, enabling close comparisons to be made between Trident experiments and VPIC simulations.

Experimental measurements of stimulated Raman scattered (SRS) light spectra find broad, in wavelength, spectral power, peaked away from linear parametric resonance. VPIC simulations show that time-resolved individual bursts of kinetic-SRS are associated with discrete wavelengths, resulting from trapping-induced downshifting of the SRS-coupled electrostatic wave frequency, and that measurements of broad SRS spectra result from instrumental time-integration of discrete bursts of SRS spectral power. The observed off-resonance peak, is shown to result from time-integration over several bursts of frequency shifted SRS. Additionally, experimental measurements also show that SRS spectral width increases, scaling approximately linearly, with increasing peak laser intensity. Both 1D and 2D VPIC simulations confirm the observed linear scaling of SRS spectral width with peak intensity at low and moderate laser intensities, and predict that the SRS spectral width saturates at large peak laser intensities.

*This work conducted under the auspices of the US DOE.

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Backward stimulated Raman and Brillouin scattering of laser in the trapping regime: Effects of collisions and seed amplitude

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In the interest of developing a validated predictive model of laser-plasma interaction to aid in design of inertial confinement fusion experiments, VPIC simulations of stimulated scattering of laser in the trapping regime are performed in single- and multi-speckle, mm-scale plasma media. In this study, a binary collision model[1] is employed within VPIC to sample the Fokker-Planck collision operator and examine the influence of collisions on stimulated Raman and Brillouin scattering. A suite of 2D VPIC simulations have been performed on the heterogeneous multi-core supercomputer, Roadrunner, to validate the physics using both LANL Trident short-pulse, signal speckle experiments[2] in the strong laser intensity regime (peak intensity > 10^{16} W/cm^2) and Raman amplification experiments on Jupiter laser facility at LLNL[3] where average laser intensity is lower: ~10^{14} W/cm^2. Nonlinear saturation by electron plasma wave bowing and self-focusing[4] from trapped electron nonlinear frequency shift is observed in simulations of both experiments; quantitative agreement is obtained in the amount of back-scatter from a solitary laser speckle and speckle fields. Nonlinear SRS saturation in mm-scale plasma is observed by increasing the seed intensity; in the weak seed intensity limit, SRS backscatter is sensitive to the collisionality. Furthermore, the presence or absence of SBS may depend sensitively on the collisional heating of the electrons and transverse electron temperature fluctuations. Strong trapping is demonstrated for the first time in mm-size plasma with average laser intensity 10^{14} W/cm^2 and backscatter seed of order 0.1%. VPIC modeling of overlapping beams in the hohlraum LEH region may reveal which designs may similarly amplify SRS originating beyond the LEH, even though single beam intensities are insufficient to achieve significant gain in the LEH.

* LANL Guest Scientist.

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Revisiting Landau damping for finite plasma parameters

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We investigate through theory and particle-in-cell simulations the Landau-damping of plasma waves in a plasma with finite plasma parameter (finite number of particles). We concentrate on the linear regime where the asymptotic damping rate is much bigger than the bounce frequency. In this regime the waves are typically very small and below the thermal noise. We simulate these condition using 1D and 2D electrostatic PIC codes (BEPS), noting that modern computers now allow us to simulate cases where (nld = [1e2;1e6]).

We study these linear waves by using a subtraction technique in which two simulations having identical random number generation seeds are carried out. In the first, a small amplitude wave is excited. In the second simulation no wave is excited. The results from each simulation are subtracted to provide a clean signal that can be studied. Since the Landau derivation does not provide a clear understanding of the physics of the damping, we derive the Landau damping rate using a Lagrangian approach based on energy conservation. This method provides the time-dependent resonance curve and the energy spectrum of the particles in the damping process. As the theory predicts, the simulations show that the damping occurs in two stages, an initial transient followed by asymptotic decay (Landau's formula). The model is equivalent to a Vlasov description of the plasma, which assumes an infinite number of particles per Debye length (infinite plasma parameter). However there are two main effects that can be associated with finite values for the plasma parameter. First, as the plasma parameter is decreased, the number of particles per Debye length (or per wavelength) gets lower and the tail of the averaged distribution is no longer smooth. Therefore, the number of resonant electrons can be small for linear waves, and we will show how the damping changes as a result of having few resonant particles. The second effect, due to the electric field fluctuations (thermal noise), causes the particles to diffuse and eventually destroys the damping. The quantity of study is the correlation time or the life time of a particular mode which depends on the plasma parameter and wave number. The correlation time is estimated and then compared with the numerical results. A surprising result is that even for very large values of the plasma parameter for which the Vlasov description is usually assumed to be valid, non-Vlasov discreteness effects are important.

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Nonlinear Optics of Plasmas: Exciting Research Prospects in High Energy Density Laboratory Plasmas*

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At the November 2009 Research Needs Workshop (ReNeW) for High Energy Density Laboratory Plasmas, several exciting prospects were identified for future research directions in nonlinear optics of HED plasmas (NLOP). Of the 5 Grand Challenge Questions arising from this workshop, two questions in particular have strong research connections to NLOP: "Can transient intense flow of energy and particles, unconstrained by conventional material limits, be manipulated and exploited?" and "How does self-organization arise with high-energy-density matter?" The exciting research directions for NLOP identified in the HEDLP ReNeW report will be summarized. The research needs, including facility requirements, novel diagnostic capabilities, theory and computing, will be discussed, and connections between the NLOP research opportunities and the Grand Challenge Questions will be drawn.

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Two Plasmon Decay in Transversly Localized Laser Hot Spots From Theory to Direct Thomson Scattering Measurements and 3/2 Harmonics Signature on Trident for Direct Drive and Shock Ignition

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Recent simulations by Tsung et al., using the explicit PIC code OSIRIS, have shown that the High Frequency Hybrid Instability (HFHI) is easily excited, beyond the pure two plasmon decay ($2\omega_p$) and pure Raman sidescattering modes. For the latter two limiting cases, one daughter wave is purely electrostatic or longitudinally polarized (fully described in terms of an electrostatic potential, ϕ), while the other is either purely electrostatic as well, which gives us $2\omega_p$, or else purely electromagnetic or transversely polarized (fully described by a vector potential, $\mathbf{A}$), which gives us Stimulated Raman Side Scattering (SBSS). As the quarter critical density is approached from below, in between these two limits there exist instabilities which have as their small $k_\perp$ daughter wave, one whose polarization is not fixed a priori but allowed to optimize the growth rate of the instability. The sequence of such modes which bridge the gap between SRSS and $2\omega_p$ make up the HFHI (modes that have non-zero $\mathbf{A}$ and ϕ). This has been known theoretically since the early 1990s [1,2] but never before seen in computer simulations.

New experiments on the Trident laser at Los Alamos with a $1\mu m$ single hot spot beam with a psec time scale pulse width have recently been conducted where a Nitrogen gas jet was used with a nsec pulse $0.53\mu m$ beam to create the plasma. Direct Thomson scattering measurements of the electron plasma waves created by the single hot spot pump beam as well as 3/2 omega radiation generated by scattering off these plasmons are the primary diagnostics. Our goals are to establish for the first time the nature of the modes that are excited as a function of intensity in this short pulse regime. Using STUD pulses to modulate the laser intensity in order to control the growth of these modes is the goal we will address in future experiments for which this is a first step.

**This work was funded in part by the DOE joint NNSA-OFES HEDLP Program and by a DOE OFES SBIR.

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Laser plasma physics important for NIF hohlraums*

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An improved understanding of laser plasma interactions in ignition-scale hohlraums will help optimize implosion experiments. Some important laser plasma physics especially relevant to large gas-filled hohlraums irradiated by many overlapping laser beams is discussed. The sensitivity of the stimulated Raman scattering to plasma conditions (and so to the electron heat transport) is simply illustrated. The importance of including overlapped laser beam effects is also illustrated with simple calculations of cross beam energy transfer[1] and cooperative scattering[2]. Seeding[3] of the cooperative scattering highlights the need to better understand the angular dependence of the Raman scattering at higher densities as well as nonlinear effects on the spectrum of the scattered light. Examples are given. A simple calculation is also given to illustrate the potential effects of Raman inflation. To understand the consistency of the inferred suprathermal electron generation with the measured Raman scattering, it is important to adopt a broader picture in which the heated electron temperature is a function of the density at which the scattering occurs. In recent experiments many of the suprathermal electrons would then have a temperature significantly less than ~30keV (which had been the lore) and so be less of a preheat threat. Finally some potential ways to mitigate SRS are discussed, including the use of narrower laser beams and increasing the electron temperature in various ways.

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Saturation, laser absorption and hot electron generation in two-plasmon decay instabilities in inertial confinement fusion*

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We present recent results from 2D PIC simulations using OSIRIS on long-term (~10 ps) nonlinear behaviors of two-plasmon decay (TPD) instabilities for OMEGA-relevant parameters. The saturation level of electro-static fields is found to depend on the level of ion density fluctuations, and is not sensitive to linear growth rates. A simplified 4-plasmon model is derived to show how the ion density fluctuations may stop TPD growth. A new fluid code based on this model is developed to study the coupling of plasma waves due to static ion density fluctuations. Laser absorption is found to be larger when the TPD threshold is exceeded by a larger factor. Pump depletion is also observed. To study the effects of laser speckles on TPD, we have also done PIC simulations with multiple Gaussian beams to compare laser absorption and hot electron generation with the results of plane wave simulations. Electron acceleration from speckle to speckle is observed.

*This work was supported by U.S. Department of Energy under Grants Nos. DE-FG02-06ER54879, DE-FC02-04ER54789, and DE-FG52-09NA29552, and Cooperate Agreement No. DE-FC52-08NA28302.

40th Annual Anomalous Absorption Conference
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Particle-in-cell Simulations of Stimulated Raman Re-scattering*

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Stimulated Raman backscatter (SRBS) is a threat to the National Ignition Facility (NIF) because it can scatter the incident laser energy and generate hot electrons that can preheat the target. While SRBS of the incident laser has been the focus of most research, we present particle-in-cell simulations that illustrate how SRBS of scattered light (rescatter) may also play a role in NIF-relevant physics. We find that SRBS of backscattered light can reduce the total reflectivity levels that are measured outside the hohlraum and that SRBS of forward scattered light produces higher energy electrons than SRBS of the incident laser, due to the higher phase velocity of the rescattered plasma wave. Of potentially more damaging consequence, we find that electrons that are accelerated by rescatter of forward SRS can feed into the forward scatter itself and be further accelerated to even higher energies. Due to the different wavelengths of the plasma waves involved in rescatter, both types of rescatter can occur in regions of the plasma that have high electron temperatures where SRBS of the incident laser does not occur due to the high plasma wave damping rate.

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The Nature of Absolutely and Convectively Unstable Modes Near the Quarter Critical Surface of Inertial Fusion Energy Targets.

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For future inertial fusion energy (IFE) targets, high T_e plasmas irradiated with high intensity (in the order of 10^{15}W/cm^2) laser will be the norm. Under these scenarios the high frequency hybrid instability (HFHI) where the laser decays into a forward going plasma wave and a backward going wave with a mixed (both electrostatic and electromagnetic) polarization very close to the quarter critical surface become important. In addition, at lower plasma densities, convectively unstable modes can also be excited and create lower temperature hot electrons with large perpendicular component. The relative importance of absolutely unstable HFHI modes, absolutely unstable 2ωp modes, and convectively unstable 2ωp modes in IFE relevant plasmas is investigated. We will investigate the robustness of these modes under the influence of an adiabatically rising laser and/or mobile ions. Nonlinear effects such as hot electron production, ion density perturbation, and the generation of odd-half harmonics will also be discussed.

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Multibeam SRS modeling with pF3d*

C. H. Still, E. A. Williams, A. B. Langdon, D. E. Hinkel, and S. H. Langer

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Last Fall, the first energetics campaign at the National Ignition Facility successfully demonstrated the ability to achieve the symmetry and radiation drive necessary for an ignition implosion[1]. One of the employed diagnostics delivered time-resolved wavelength spectral data of the stimulated Raman Backscatter (SRS). An accurate SRS model using the laser-plasma interaction code pF3d[2] is not possible without incorporating the nearest-neighbor 23° quads[3]. Doing so requires modeling the interaction of multiple beams, some of which propagate non-normally to the Z-axis. This introduces a numerical absorption error, which can be controlled by increasing the accuracy of the partial cell light advection algorithm, and by increasing the spatial resolution of the simulation. We report on the modifications made to pF3d that enable modeling of multiple beams, and show some preliminary results.

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LLNL-ABS-429833

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Hot electron measurements and Stimulated Raman Backscatter on NIF*

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In this presentation we will give a detailed description of how the low energy channels of the hot electron diagnostic (FFLEX) can be related through a two-temperature fit to the total amount of Stimulated Raman Backscatter. In particular, we can infer backscatter on the shallowest cone (23 Deg) where no backscatter diagnostic is available. This allows us to reconcile various measurements of the energy balance of the hohlraum when the frequency of beam cones was changed. The higher energy component (related to preheat) will be discussed as will plans to add a Near Backscatter Imager to the 23.5 degree beams to directly measure the backscatter on this cone in future experiments

* This work was performed under the auspices of the U.S. DOE by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344 and by Los Alamos National Laboratory under contract DE-AC52-06NA25396.

40TH ANNUAL ANOMALOUS ABSORPTION CONFERENCE
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Examination of Sensitivities for Strong Shocks in Cassio

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Abstract

In this paper we present results of a sensitivity study for strong shocks in the HED code Cassio. Cassio is an eularian radiation-hydrodynamics code being developed at Los Alamos to study HED physics. It can be used with both tabular and analytic equations of state and opacities. The radiation transport can be either grey diffusion, multi-group diffusion or multi-group IMC. The material models can be either two-temperature, material and radiaiton, or fully three-temperature, separating the electron and ion temperatures. We examine the behavior or strong shocks driven by energy sourced into an outer region. We explore not only hydrodynamic convergence behavior but also the effect of other physics choices on the shock and compression behavior in Cassio.

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Nonlinear, Local Kinetic Damping of Finite-Width Plasma Waves Relevant to Stimulated Raman Scattering*

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Recent particle-in-cell (PIC) simulations (L. Yin *et al.*, PRL **99**, 265004 (2007)) of stimulated Raman scattering (SRS) in multiple dimensions indicate that plasma wavefront bowing and localization are important potential nonlinear saturation mechanisms. We present here the results of detailed PIC simulations in which an external, ponderomotive impulse driver generates finite-width plasma waves. These simulations allow careful study of wave behavior over a wide range of parameters. We find that local, kinetic damping effects operate in conjunction with wavefront bowing to localize large-amplitude plasma waves along their axis. We also discuss the flow of energy in plasma waves. The simulations are performed using an electrostatic PIC code.

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Abstract for the

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Mega-joule experiments on the National Ignition Facility - on the road to produce a microscopic star in the laboratory*

SIEGFRIED GLENZER

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Abstract

With completion of the National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory the quest for producing a burning fusion plasma has begun. The goal of these experiments is to compress matter to densities and temperatures higher than the interior of the sun to initiate nuclear fusion and burn of hydrogen isotopes. In the first indirect-drive hohlraum experiments on NIF, we have demonstrated symmetric capsule implosions at unprecedented conditions of mega-joule laser energies. 192 simultaneously fired laser beams heat ignition hohlraums to radiation temperatures of 3.3 million Kelvin compressing 2-millimeter capsules by the soft x rays produced inside the hohlraum. Self-generated plasma-optics gratings on either end of the hohlraum tune the laser power distribution on the hohlraum wall producing symmetric x-ray drive as inferred from capsule self-emission measurements. These experiments indicate conditions suitable for compressing deuterium-tritium filled capsules with the goal to produce a microscopic star in the laboratory.

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Anisotropic distribution of hard x-rays from the two-plasmon-decay hot-electron distribution*

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Target preheat caused by hot electrons from the two-plasmon-decay (TPD) instability may reduce the fuel areal density ρR in direct-drive implosions. The directionality of these hot electrons is important for the simulation of target preheat due to these electrons. Measurements of bremsstrahlung hard x rays from surrogate planar targets show a strong forward emission in both a fixed four-channel hard x-ray detector and a new x-ray image-plate detector placed close to the target. The measured forward peaked x-ray distribution is believed to be the result of cooperative multibeam TPD. The observed bremsstrahlung emission asymmetry will be compared with a bremsstrahlung emission model that assumes hot electrons are produced within an angular cone with an exponential energy distribution.
The implications of the observed anisotropic distribution will be discussed.

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Anomalous stopping due to macro-particles in PIC simulations

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An equation for energy transfer from relativistic charged particles to cold background plasma in two-dimensional particle-in-cell simulation codes is derived. This energy transfer is due to the electric field of the wake set up in the background plasma by the relativistic particle. The enhanced stopping is dependent on the q^2/m of the relativistic particle and therefore simulation macro-particles with high charge but identical q/m will stop more rapidly. We present two-dimensional particle-in-cell simulations of test particles, distributions of particles, and fast ignition simulations to show how the anomalous stopping of macro-particles may affect the results of these simulations depending on the number of particles per cell and cell size.

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Beyond 1D: Algorithmic Advances for More Tractable Vlasov Simulation*

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Direct discretization of the continuum Vlasov equation leads to computationally prohibitive discrete problems due to the geometric growth of computational expense with dimension. Accordingly, direct Vlasov simulation has mostly been limited to 1D, and Particle-In-Cell (PIC) methods, with their more efficient phase space representation, have become the dominant kinetic simulation approach. There are, nevertheless, situations where a multidimensional Vlasov simulation capability would prove useful, and the growth of available computational resources has made feasible simulation above 1D.

Increases in computational hardware, however, are insufficient to allow for routine Vlasov simulation in two dimensions; improved numerical algorithms are also required. In the VALHALLA project at LLNL, we have been developing advanced, scalable algorithms for the Vlasov-Maxwell system that improve not only the overall computational efficiency but the solution fidelity as well. Our approach is based on a new high-order, nonlinear finite volume discretization that is discretely conservative, controls oscillations, and can explicitly enforce positivity.[1] This method is well-suited for block-structured adaptive mesh refinement (AMR) and has excellent parallel scaling properties. We have implemented this scheme within the parallel AMR framework SAMRAI.[2] By reducing the number of discrete unknowns, high-order discretizations and AMR can increase the efficiency of direct Vlasov simulation.

We report on our new algorithms for Vlasov-Maxwell discretization with adaptive mesh refinement. Algorithms required for AMR on solutions that couple domains of different dimensions will be discussed, as will open issues in the efficient use of AMR in dimensions above three. Physically-motivated results in 1D and 2D will be presented to demonstrate our progress in improving algorithmic efficiency as well as the types of simulations that are enabled by this new technology.

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The Onset of Inflation and the Effects of Seed Pulses on SRS*

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In ICF, it is important that laser light be absorbed where it is aimed. Stimulated Raman Scattering (SRS) will potentially be detrimental to ICF because it can reflect and scatter light as well as generate hot electrons, but the domain of validity for which current theories of SRS reflectivity are valid is unknown. One such theory, kinetic inflation[1], is of particular interest because it predicts SRS reflectivities that are much larger than linear gain predictions for laser intensities below the absolute instability threshold. Using the particle-in-cell (PIC) code OSIRIS, we performed 1D simulations with pump intensities of $\sim 10^{14}\frac{W}{cm^2}$ and a counter-propagating seed of intensity $\sim 10^{10} - 10^{15}\frac{W}{cm^2}$ to study the onset of kinetic inflation in backward SRS for ICF-relevant plasmas. When we used a continuous seed, we found that the onset of inflation was sharply determined by the pump intensity and the seed wavelength. We will discuss the nature of this inflation onset and factors that prevent the inflation from occurring. We performed further simulations using seed pulses of varying wavelength, intensity, and duration. When using pulses of short duration, the seed pulse underwent linear gain as it crossed the box, and we observed a linear gain spectrum similar to that predicted by linear theory. As we increased the seed intensity, we continued to observe linear gain when the maximum seed pulse intensity was of the same order of magnitude as the pump intensity. However, we observed inflation-like behavior of the pump from the residual plasma wave a sufficient time after the seed exited the system when using seeds of low and high intensity. As we increased the seed duration, the inflation-like behavior began to occur while the seed was still in the system. We compare and discuss the linear gain seen in simulations with linear theory. We also use a subtraction technique[2] to observe the plasma wave for low seed intensities. Simulations results for various seed intensities, wavelengths, and durations will be presented.

*This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 and by the University of California, Los Angeles under Grant DE-FG52-09NA29552.

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Studies of Waves and Turbulence in Tokamak Plasmas with Phase Contrast Imaging and Comparisons with Code Predictions by Synthetic Diagnostics*.

M. Porkolab, K. Arai, P.T. Bonoli, J. Dorris, E. Edlund, P. Ennever, L. Lin, Y. Lin, C. Rost, N. Tsujii, S. Wukitch, Plasma Science and Fusion Center, MIT.

We present an overview of recent work using Phase Contrast Imaging (PCI) to measure RF waves and turbulence in tokamak plasmas (C-Mod and DIII-D). The results will be analyzed with various state of the art codes by means of synthetic diagnostic techniques [1]. Experimental results will be presented on Alfven wave cascades driven by energetic ion tails associated with ICRF minority heating in C-Mod, low frequency turbulence and transport associated with density and temperature gradients in C-Mod and DIII-D, and mode converted ion cyclotron waves (ICW) and ion Bernstein waves (IBW) in the presence of high power RF waves launched in the ion cyclotron range of frequencies (ICRF). For example, Alfvén wave phenomena will be compared with the NOVA and NOVA-K codes [2], low frequency turbulence and related transport will be compared with predictions of GYRO and TRANSP [3], and mode conversion phenomena in the ICRF regime will be compared with AORSA and TORIC [Ref 4]. In the future such techniques will receive increased emphasis in MFE research to validate large codes for more reliable predictive capability in view of the forthcoming Fusion Simulation Project (FSP).

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Tuesday, June 15, 2010

Radiation Hydrodynamics (I)

Session Chair: N. Meezan, LLNL

T. Collins, LLE (Invited)
S.V. Weber, LLNL
R.E. Olson, SNL
P.A. Amendt, LLNL
C.K. Li, MIT

UNM LOS ALAMOS

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Preparing for polar drive at the National Ignition Facility*

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Polar drive (PD)[1] will make it possible to conduct direct-drive-ignition experiments at the National Ignition Facility (NIF) while the facility is configured for x-ray drive. An optimal drive uniformity is obtained by modifying the laser illumination through beam repointing and laser-pulse and spot shapes. Implosion uniformity can be improved using target modifications such as ice-shimming to remove mass from the equatorial region. The polar-drive concept is being tested on the OMEGA Laser System. In these experiments, 40 OMEGA beams, arranged in six rings to emulate the NIF x-ray-drive configuration, are used to perform direct-drive implosions of CH and SiO_2 shells filled with D_2 and DT gas. The results of two-dimensional (2-D) PD *DRACO* simulations of the OMEGA experiments are in good agreement with experimental yields and x-ray radiographs. Recent experiments on the NIF, designed to commission neutron diagnostics, have successfully employed PD "exploding pusher" targets for which the neutron yield is primarily due to convergence of the main shock. *DRACO* simulations of these experiments reproduce the important features of the time-resolved x-ray emission and the overall neutron yield. Drawing from the success of these experiments, simulations of a PD ignition design will be shown that employs a wetted-foam ablator (for higher laser-energy coupling), and a single decaying-shock picket-pulse shape for adiabat shaping will be shown. This design has a 2-D predicted gain of 17. An ignition-scale design, employing a solid-CH ablator and three relaxation pickets to facilitate experimental shock timing, is being developed.

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Modeling of Capsule Data from the First NIF Experiments*

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The first series of NIF ignition campaign experiments, called the hohlraum energetics campaign, was performed in August – December, 2009. We have performed simulations of a selected set of implosions in order to understand the capsule performance data obtained in those experiments. Symmetry capsules (SymCaps) with Ge-doped CH ablators filled with He/D gas were used for these shots. Capsule data include time-integrated and gated x-ray images of the imploded cores, neutron yields, burn ion temperatures, and spectra of D^3He protons. Hohlraum data such as x-ray drive, backscatter, and hot electron emission measurements will be presented in other talks. Expected capsule degradation mechanisms were examined such as hot electron preheat, gold M band radiation, variations in the drive pulse, and mix. Our analysis suggests that mix arising from isolated defects and clusters of isolated defects was a significant factor in the higher performance implosions. This result has lead to efforts to improve and better characterize the surface finishs of the capsules which will be used for upcoming ignition experiments.

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X-Ray Conversion Efficiency in NIF Vacuum Hohlraum Experiments*

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X-ray fluxes measured in the first 96 and 192 beam vacuum hohlraum experiments at NIF were significantly higher than predicted by pre-shot simulations employing the default XSN average atom atomic physics and highly-limited electron heat conduction. For agreement with experimental data, it is found that the coronal plasma emissivity must be simulated with a DCA model that accounts for X-ray emission involving all of the significant ionization states. In addition, it is found that the default electron heat conduction flux limit of f=0.05 is too restrictive, and that a flux limit of f=0.15 (or even the free-streaming limit, f=1.0) will result in a much better match with the NIF vacuum hohlraum experimental data. Overall, the combination of increased plasma emissivity and increased electron heat conduction results in a reduction in coronal plasma energy and, hence, a high (~90%) X-ray conversion efficiency.

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The potential role of plasma barotropic diffusion on ICF implosion performance with thermonuclear fuel mixtures*

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The generation of strong, self-generated electric fields (10^8-10^9 V/m) in direct-drive, inertial-confinement-fusion capsules has been reported [1]. A candidate explanation for the origin of these fields based on charge separation across a plasma shock front was recently proposed [2]. The question arises whether such electric fields in imploding capsules can have observable consequences on target performance. Two well-known anomalies come to mind: (1) an observed ≈2× greater-than-expected deficit of neutrons in an equimolar D^3He fuel mixture compared with a hydrodynamically equivalent DD [3] and DT [4] mixtures, and (2) a similar shortfall of neutrons when trace amounts of argon are mixed with DD fuel in indirect-drive implosions [5]. A new mechanism based on barodiffusion in a plasma is proposed that incorporates the presence of electric fields to largely explain the reported anomalies. Barodiffusion is pressure gradient-driven diffusion and may be particularly important across shock fronts. The adaptation of fluid treatments of barotropic diffusion to the plasma state with self-generated electric fields has the important feature of distinguishing the charge states of the fuel ions. In the case of an equimolar D^3He fuel mixture, the neutron anomaly persists even with the same constituent molecular weights as in a DT fuel. However, the component charge states differ between these two fuels, driving a potentially stronger species separation across a shock front for D^3He. For Omega-scale implosions the return shock (following shock convergence at the center of the fuel) has a rather low Mach number (≈1.2-1.3) and a correspondingly broad (plasma) shock front (≈50-100 μm), leading to an appreciable scale length over which the lighter deuterium ions can diffuse away from fuel center. The depletion of deuterium fuel is estimated and found to yield a corresponding reduction in neutrons, consistent with the anomalies observed in experiments for both argon-doped DD fuels and D^3He equimolar mixtures. The reverse diffusion of the heavier ions towards fuel center also increases the pressure, resulting in lower stagnation pressures and larger imploded cores in agreement with gated self-emission x-ray imaging data [4]. The theory is applied to studying the degree of potential fractionation of THD fuel mixtures for an upcoming ignition tuning campaign on the National Ignition Facility.

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Observations of Spontaneous Electromagnetic Fields, Plasma Flows, and Implosion Dynamics in Indirect-Drive Inertial-Confinement Fusion*

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The first measurements of x-ray-driven implosions with charged particles[1] have allowed a number of important phenomena to be observed and several critical parameters to be determined. Three types of spontaneous electric fields differing in strength by two orders of magnitude (the largest ~ one-tenth of the Bohr field $ea_0^{-2} \sim 5\times10^{11}$ V/m, where a_0 is the Bohr radius) were discovered with two novel techniques that were previously unavailable, time-gated proton radiographic imaging and spectrally-resolved proton self-emission. These results, along with other new and exciting observations such as spontaneous megagauss magnetic fields, plasma flows, supersonic jets (~ 1000 km/sec, Mach number ~ 4), areal density and implosion symmetry, will have important impact on nuclear fusion ignition. They are also of fundamental scientific importance for a range of exciting new experiments in the frontier fields of high-energy-density physics, including laboratory astrophysics, space physics, nuclear physics and material sciences.

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Tuesday, June 15, 2010

Radiation Hydrodynamics (II)

Session Chair: P. Amendt, LLNL

O.L. Jones, LLNL
S.X. Hu, LLE
R.A. London, LLNL
P. Bonoli, MIT
R. Harvey, MIT

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Capsule Performance in Presence of Surface Perturbations and Drive Asymmetry*

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Traditionally calculations that included the effects of surface perturbations, fill tubes, etc. have been "capsule-only" calculations. These use a frequency-dependent radiation drive source applied at the outer spherical boundary some distance away from the capsule. The drive flux and asymmetry are extracted from a lower resolution integrated hohlraum-capsule calculation. The extracted drive is then applied to a capsule-only calculation with no surface perturbations and the capsule response is compared to the source integrated calculation. One disadvantage of this technique is that it can take several iterations of this procedure to get good agreement between the original source drive and the drive imposed in the capsule-only calculation.

In this work we developed the techniques to perform integrated hohlraum-capsule axisymmetric calculations with perturbations applied to the capsule outside surface, all the dopant layer interfaces, the ice/ablator interface, and the inside ice surface. These included surface roughness perturbations in modes up to l=30. These calculations are compared in detail with capsule-only calculations having the same drive and surface perturbations.

We show results from two applications of this calculational technique. First, the technique was applied to calculations of THD capsules for a virtual campaign. These calculations used slightly altered physics models. In addition to regular surface perturbations, some of these calculations also included surrogates for ice cracks and fill tubes. Realistic nuclear diagnostic outputs were created and then analyzed to determine the yield, the down-scatted fraction, etc. Secondly, the technique was applied to determine how well x-ray imaging techniques could measure the shape of THD capsules having rough surfaces. Simulated x-ray images of THD capsules with smooth and rough surfaces were compared.

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Two-dimensional radiation-hydrodynamic simulations of cryogenic-DT implosions at the Omega Laser Facility*

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This work reports on the analysis of low-adiabat, cryogenic deuterium–tritium (DT) implosion experiments performed at the Omega Laser Facility using triple-picket laser pulse shapes. High areal densities ($\langle \rho R \rangle$), up to $\langle \rho R \rangle \sim 300$ mg/cm^2, have been demonstrated in these implosions. The neutron yield varies from $\sim 2 \times 10^{12}$ to $\sim 6 \times 10^{12}$ (2.5% ~ 10% of one-dimensional predicted values) depending on the details of the pulse shape and laser/target nonuniformities. Nonuniformities seeded by target and laser nonuniformities and the displacement of the target from target chamber center (target offset) can, in principle, disrupt compression and neutron production. To understand these effects, each perturbation source and their combined effect on implosion performance has been systematically investigated using the two-dimensional hydrodynamic code *DRACO*. Integrated simulations of individual cryogenic-DT shots reproduce the experimental yield-over-clean (YOC) and the neutron-averaged ion temperatures. Defining the temperature-over-clean (TOC), we find that the relationship of YOC versus TOC provides an indication of how much the hot-spot volume and density is perturbed with respect to uniform conditions. Simulation results suggest that in order to increase YOC to the ignition-equivalent level of ~15% to 20% (while maintaining $\langle \rho R \rangle$ = 200 ~ 300 mg/cm^2) target offset should be limited to less than 10 μm, and short-wavelength nonuniformities from laser speckle should be reduced [by using the smoothing by spectral dispersion (SSD) technique available on OMEGA]. The $\langle \rho R \rangle$ variation caused by perturbations is within the measurement error, indicating the adequacy of a single view to infer average areal density in the presence of perturbations.

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Non-local electron heat transport in hohlraums at the National Ignition Facility*

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The first experimental campaign at the National Ignition Facility was performed in the fall of 2009 and focused on the energetics and symmetry of hohlraum targets as a step towards achieving inertial confinement fusion ignition.[1] The main goal was to study the conversion of laser light to x rays and the transport and coupling of the x rays to a spherical capsule inside a hohlraum. One component of the energy flow is stimulated Raman and Brillouin backscatter of laser light. The level and spectra of backscatter are sensitive to the ambient plasma conditions, i.e. the temperature, density and velocity. Calculations of the plasma conditions within hohlraums have previously used a flux-limited diffusion model for electron heat transport. This model breaks-down when electron mean-free-paths are comparable to or larger than plasma scale-lengths. A better model, considering non-local heat transport, has been proposed.[2] We present results of NIF hohlraum simulations using the non-local model in the Hydra radiation-hydrodynamics program.[3] The results are compared to diffusion. The non-local model gives electron temperatures approximately 25% cooler than diffusion with the usual flux limiter of 5%. Calculated quantities, such as the emitted x-ray intensity and the gain and spectra for stimulated backscatter are compared with experimental data from the 2009 NIF campaign. Based on these comparisons, we present the best current model for electron heat transport in NIF hohlraums.

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

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Integration Issues for Simulating Wave-Particle Interactions in Tokamak Plasmas*

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Radio-frequency (RF) power is widely used in present day fusion devices for plasma heating and for localized control of the pressure and current density profiles in order to access regimes of improved energy confinement time. A simulation capability that takes advantage of massively parallel computing platforms is now being developed and validated in order to optimize the use of RF actuators in present day tokamaks as well as in burning plasmas such as the ITER device. In this paper we will describe the physics and computational issues associated with the integration of different models that are needed for RF applications in the ion cyclotron range of frequencies (ICRF) and the lower hybrid range of frequencies (LHRF).

Accurate simulation of RF wave propagation and absorption requires the integration of several different physics descriptions including coupling of RF wave power from metallic launching structures in the tenuous edge plasma, the interaction of coupled waves with non-thermal populations of ions and electrons generated by the wave itself, the interaction of the waves with energetic ions due to neutral beam injection (NBI) heating or fusion processes, and treatment of wave propagation in situations where disparate spatial scale lengths exist due to mode conversion processes. The interaction of waves with energetic particles in the core is described by an approach which integrates ray tracing and electromagnetic field solvers with continuum Fokker Planck or Monte Carlo orbit codes that solve for the non-thermal particle dynamics. This integrated system is highly nonlinear and is typically solved via iteration between the wave solvers and Fokker Planck codes. The edge coupling problem can be nonlinear due to the formation of RF sheaths at metallic surfaces in the edge that can dissipate power. Furthermore, realistic solutions for the RF coupling problem are complicated even in the linear limit where it is important to account for the 3-D solid geometry of the RF launcher. Finally, the integration of realistic edge coupling descriptions with core wave physics models is still in its infancy.

In this paper we will also describe the role of applied mathematics and advanced computing in making it possible to obtain realistic electromagnetic wave field and Fokker Planck solutions. We will also describe the use of computational frameworks in order to implement this simulation capability in conjunction with other advanced simulation codes for magnetohydrodynamics (MHD) and transport.

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The Fokker-Planck Equation as Applied to RF Physics in Magnetic Fusion Energy Research*

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Both finite-difference and Monte Carlo methods are used for solution of Fokker-Planck (FP) equations for nonthermal particle distributions relevant to radiofrequency (RF) heating and current drive in magnetic fusion energy research. CQL3D[1] exemplifies the finite difference approach. Assuming toroidal symmetry of the magnetic confinement flux surfaces, and focusing on the collisional and radial transport time scales which are long compared to particle gyro- and bounce-periods, the general 6D phase-space equation is reduced to a 3D bounce-averaged (BA) FP for the particle distribution as a function of velocity, velocity pitch angle, and a radial coordinate. For the fully non-linear collision operator, the distributions must be reconstituted from the 3D BA distributions at each point along the particle orbit, to form the FP coefficients. Past CQL3D work neglected particle motion perpendicular to the flux surfaces. The principle physics in the code is Coulomb collisions, resonant wave-particle interactions giving principally velocity-diffusion, and the effects of an applied Ohmic toroidal electric field, and specified anomalous radial transport. RF physics is imported from auxiliary ray tracing or full-wave solutions for the wave fields. Results have been validated against experiment in numerous experiments. Time-implicit solution methods are by direct Gaussian elimination on each flux surface neglecting radial transport, and splitting or conjugate gradient sparse-matrix methods with radial transport. Required computer time per run is modest. Recent Monte Carlo (MC) FP work has shown the importance of finite-orbit-width (FOW) effects, in comparison with experiment[2,3]. The principle challenge in the sMC and ORBIT-RF MC codes has been accurate coupling to the diffusion from the full-wave toroidal-mode spectrum. Even with large-scale parallelization on peta-scale computers, is is challenging to obtain accurate results within available time-constraints. The CQL3D code is being upgraded for FOW effects. The critical challenge is reconstituting the distribution function at each orbit point, requiring 10^{12} lookups. Massive parallelization will by used, particularly to improve load balancing when using CQL3D-FOW in a framework operating in tandem with other physics codes[4].

*This work supported under US DOE awards DE-FC02-01ER54649 and DE-FG02-04ER54744.

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Plenary II

Session Chair: T. Kwan, LANL

L. Yin, LANL

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Three-dimensional dynamics of break-out afterburner ion acceleration using high-contrast short-pulse laser and nano-scale targets*

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Ultra-intense laser interaction with solid density carbon targets is examined in 3D VPIC simulations for the first time. It is shown that a linearly polarized laser pulse at $>10^{20}$ W/cm^2 intensity will turn a solid density, nm-scale target relativistically transparent and begin an epoch of dramatic acceleration of ions. Called the Break-Out-Afterburner, or BOA[1], this mechanism leads to order-of-magnitude greater ion energy and beam currents. The BOA lasts until the electron density in the expanding target reduces to the critical density in the non-relativistic limit. A striking feature of the BOA mechanism is that the ion beam symmetry is broken, with the production of lobes in the direction orthogonal to the laser polarization and propagation directions[2], along which the highest ion beam energy is observed. These ion beam lobes have been measured on recent Trident experiments[3]. A simple analytic model for the production of ion beam lobes has been obtained and has been shown to be in good agreement with VPIC simulations. Moreover, other features of the BOA, e.g., the existence of an optimal target thickness for given laser and target density and the propagation of light and heavy ion species at cpmparable speed (impossible to obtain in other laser-ion acceleration mechanisms such as target-normal sheath acceleration) have been found in VPIC simulations and shown to be in quantitative agreement with Trident experiments[3].

* This work conducted under the auspices of the U.S. Department of Energy by the Los Alamos National Security, LLC Los Alamos National Laboratory.

♦ LANL Guest Scientist.

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Poster Session II
EOS and FI

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TPIE: Thomson Parabola Ion Energy Analyzer*

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A new, versatile Thomson parabola ion energy (TPIE) analyzer has been designed, constructed, and used at the OMEGA-EP facility[1]. Multi-MeV ions accelerated from EP targets are transmitted through a W pinhole into a (5- or 8-kG) magnetic field and subsequently through a parallel electric field of up to 30 kV/cm. The ion drift region may have a user-selected length of 10, 50, or 80 cm. With the highest fields, 500-MeV C6+ and C5+ may be resolved. TPIE is TIM-mounted at OMEGA-EP and can be used opposite either of the EP ps beams. The instrument runs on pressure-interlocked 15-VDC power available in EP TIM carts. It may be inserted to within several inches of the target to attain sufficient flux for a measurement. For additional flux control, the user may select a square-aperture W pinhole of 0.004" or 0.010". The detector consists of CR-39 backed by an image plate. A fully relativistic design code for calculating ion trajectories was employed for design optimization. After first use, it was seen that the agreement of code predictions with the actual ion positions on the detectors was excellent. Subsequently, detector noise has been effectively mitigated with the installation of a shroud to cover the top of the instrument. The code has been modified to include the effect of the fringing electric field of the Rogowski-shaped electrodes[2]. Details of the design code, experimental design features, and ion spectral results from OMEGA-EP will be discussed.

*This work has been conducted under the auspices of the United States Department of Energy, contract number DE-AC52-06NA25396.

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Electrothermally generated filaments in laser–solid interactions*

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In the overdense plasma just inside the ablation surface, where there is a strong heat flow (≥3% of free-streaming) and where the electron-ion mean-free-path is less than the collisionless skin-depth, the electrothermal (ET) instability[1] can grow with several e folding times. As a result, magnetized filaments of hot, low-density plasma with a separation of the order of 10- to 100-μm convect with the ablating plasma. Such filaments have been observed by Willi and Rumsby[2] (using laser shadowgraphy) in the corona and Borghesi, Schiavi, and Willi[3] (using MeV proton radiography) close to the ablation surface. There are three main effects that such filaments have: (1) In the ablation surface the density perturbations will seed Rayleigh–Taylor instabilities; (2) Between the critical surface and ablation surface the toroidal magnetic fields encircling each filament will affect the electron transport in a spatially nonuniform way; and (3) In the coronal region the density dips in each filament will affect the paths of the laser rays by refraction. The growth of the ET instability and its consquences are examined in this paper.

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Challenges in self-consistent full wave simulations*

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Magnetically confined plasmas can contain significant concentrations of non-thermal plasma particles arising from fusion reactions, neutral beam injection, and wave-driven diffusion in velocity space. Initial studies in one-dimensional and experimental results show that non-thermal energetic ions can significantly affect wave propagation and heating in the ion cyclotron range of frequencies (ICRF). In addition, these ions can absorb power at high harmonics of the cyclotron frequency where conventional two-dimensional global-wave models are not valid. In this work, the all-orders global-wave solver AORSA[1] is generalized to treat non-Maxwellian velocity distributions. Quasilinear diffusion coefficients are derived directly from the wave fields and used to calculate energetic ion velocity distributions with the CQL3D Fokker-Planck code[2]. Self-consistency between the wave electric field and resonant ion distribution function is achieved by iterating between the global-wave and Fokker-Planck solutions. These same techniques have been applied to wave propagation in the lower hybrid range of frequencies (LHRF) to include the effects of wave diffraction and focusing with non-Maxwellian wave generated electrons[3].

Advances in algorithms and the availability of massively parallel computer architectures have permitted the solving of the Maxwell-Vlasov system for these large problems. We will discuss the various modeling advances that have led to the capability including various memory management approaches, physics motivated algorithm adaptations appropriate to the LHRF and ICRF, and improvements in the matrix solvers to minimize communication overhead when using 10000s of cores on leadership class computer platforms.

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A low-noise δf particle-in-cell method for simulating ICRF physics*

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Full wave codes such as AORSA and TORIC have been used to model RF heating of plasma with Maxwellian velocity distributions for which the local plasma response approximation is valid. When this approximation is not valid, the validity of the results is to be questioned and an alternative approach is necessary. We use an approach for modeling ICRF physics that uses the δf particle-in-cell method for ions and a fluid model for electrons. This allows us to step over the time scales associated with the electron plasma wave and focus on the ion time scales. However, our original attempt at using the δf particle-in-cell method to simulate the canonical 1D kinetic benchmark problem[1] containing ICRF was not successful. Furthermore, the simulations were noisier than was expected given the δf particle-in-cell method. Recently, we have explored a new approach to the δf particle-in-cell method based on the work of Hu and Qin[2]. The approach of Hu and Qin suggests loading particles on *Kruskal rings* in velocity space leading to a very low-noise approach. We reinvestigated the canonical 1D kinetic benchmark[1] using the new low-noise approach and successfully simulated mode conversion of a launched fast wave into an ion Bernstein wave in 1D. Furthermore, the signal-to-noise ratio was much higher than with the original δf particle-in-cell method. We have also explored preliminary 2D simulations and observed encouraging results. For the 2D problems we will report on parallel performance of the approach for 1000s of processors and address future work on improving the performance of the code.

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Picosecond scale interaction of energetic ultra-intense laser pulses with plasma gradients*

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We characterize the interaction of ultra-intense kilojoule laser pulses with large-scale plasma gradients, using 2D and 3D particle simulations. Key questions will be addressed, such as the picosecond temporal evolution of the laser energy conversion into hot electrons, their beam divergence, scaling with pre-plasma, laser intensity and wavelength, and the effect of self-generated electric and magnetic fields on the injected electron distribution. We finally discuss implications for fast ignition.

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Electron Acceleration by High Intensity Lasers at Sharp Matter Interfaces*

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The acceleration and heating of electrons by an intense laser normally incident on a steep over- dense plasma interface is investigated using the particle-in-cell code OSIRIS. We show that the energetic electrons are generated by the laser's electric field in the vacuum region within a quarter wavelength of the surface and that only those electrons which originate within the plasma with a sufficiently large transverse momentum can escape the plasma into the vacuum region. No heating occurs for initially cold plasmas until the plasma is heated by other mechanisms. The maximum energy generated by this mechanism is 2eA where e is the charge of an electron and A is the peak vector potential of the laser. The simulations show that this mechanism relies on the standing wave structure created by the incoming and reflected wave and is therefore very different for linear and circularly polarized light.

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LSP modeling of the LPI and the resulting hot electron divergence and K_α emission in slabs and buried cones*

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Fast Ignition (FI) requires the efficient conversion of laser energy to particle kinetic energy followed by particle propagation into the target. If the particle beam divergence is too large, FI becomes impractical; likewise if the particle energy is too low or too high. Naturally, this problem has been the focus of recent experiment with more underway or planned for the near future. We have used the hybrid PIC code, LSP,[1] to study this problem for 1 μm wavelength, sub-ps laser pulses at an intensity of 4×10^{19} W/cm^2 incident on metal targets and generating 'hot' electrons. K_α radiation emitted from the target, or from flours embedded in the target, is an important diagnostic tool used in experiment, but it is not clear how well this diagnostic reveals the properties of the hot electrons. For example, the size of the K_α spot in fluors close to the critical surface where the laser energy is absorbed can be an order of magnitude larger than the laser spot itself.[2]

We have performed 2D Cartesian simulations of a laser pulse incident on copper and aluminum targets with an initial pre-plasma present of varying scale. The laser plasma interaction (LPI) and subsequent transport of hot electrons and 'return current' is modeled self-consistently without separation into LPI and transport phases. We use 800 μm x 200 μm targets or larger. We find for targets with a small scale length pre-plasma (~1 μm) that the K_α radiation from embedded flours provides a good estimate of the hot electron spatial distribution, but becomes misleading for larger scale lengths. We treat slab and 'buried cone' geometries that mimic the use of a reentrant cone for FI and we have some results working in 3D. Finally, we address constraints that should be satisfied to treat this problem using LSP.

*This work is supported by the U.S. Department of Energy under contracts DE-FG02-05ER54834 and DE-AC52-07NA27344, and by an allocation of computing time from the Ohio Supercomputer Center.

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40th Annual Anomalous Absorption Conference
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Multi-Center Electronic Structure Calculations For Plasma Equation of State*

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The generation of plasma equation of state data over wide ranges of temperature, density and material composition is a computationally intensive task. For this reason there is a traditional reliance on single 'average-ion-in-jellium' models and an assumption of ideal gas mixing of components. However in the warm dense mater regime the electronic wave-function behavior strongly reflects the influence of multiple ion centers. The electronic structure about any nuclear site is then no longer well approximated by a neutral ion sphere in an effective spherically symmetric field.

We report on an alternative approach utilizing solid-state multi-center scattering techniques, generalized to finite temperatures, for computing electronic structure. The plasma is thereby modeled as ensembles of pseudo crystals, with each lattice-cell consisting of many amorphously positioned nuclei.

This approach has the advantage of handling mixtures at a fundamental level without the imposition of ad hoc continuum lowering models, and allows bonding and charge exchange, as well as incorporating multi-center effects in the calculation of the continuum density of states.

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40TH ANNUAL ANOMALOUS ABSORPTION CONFERENCE
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An average atom model with electronic bands

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Quantum molecular dynamics (QMD) simulations provide an accurate but computationally expensive method of calculating the properties of warm dense matter (i.e. densities of the order of solid density, with temperatures of the order of tens of thousands of Kelvin). The method is useful for benchmark calculations but can not be reasonably used to produce full EOS tables.

One notable alternative model is Liberman's average atom (AA) in jellium. This model can be used to do calculations over a wide parameter range (density, atom type, temperature) and has been seen to produce reasonably accurate results when compared to QMD simulations and experiment. An essential feature of this model is that bound states are treated as atomic style single eigenvalue orbitals, even at high densities. This physical picture is at odds with the accepted solid state model of bands of electronic eigenvalues for non-isolated atoms, and leads to the phenomena of resonance states when bound states pressure ionize. These resonance states have to be carefully tracked numerically to avoid spurious results. They therefore increase computation time, while in the end they are smeared out to remove spikes in DOS and conductivities.

At this meeting we will propose an AA approximation which draws on the successes of QMD by modeling electronic bands. In this model we avoid altogether resonance states and their associated problems. The model is validated with calculations on Al over the metal to non-metal transition regime. Comparison will be made with QMD simulations and with AA in jellium.

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Subwavelength nanobrush target to efficiently accelerate and collimate fast electrons *

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The property of fast electrons' transportation in a subwavelength nanobrush target is investigated experimently and theoritically. The experiment is hold at SILEX-I laser facility with intensity of $7.9 \times 10^{18}\,\mathrm{W/cm^2}$. Highly collimated fast electron beam with divergence angle nearly zero and yield more than 3 times higher are realized compared to that of the plane target. Two-dimensional particle-in-cell (PIC) simulations shows that the fast electrons will be efficiently accelerated and collimated by strong transient electromagnetic fields created at the wall surfaces of nanobrushs compared to plane target. Both experiment and simulation show that unique subwavelenght nanobrush structure will generate fast electrons efficiently and collimate them.

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Proton energy loss measurements in high density, low temperature plasma*

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There is a great need for experimental verification of energy loss physics in plasma modeling codes. This is particularly true in the moderately-strongly coupled regime. In this regime, charged projectiles no longer under go binary collisions with the plasma medium. Under this condition, the charged projectile experiences collisions with multiple particles simultaneously (many-body collisions).

In inertial confinement fusion and stellar interiors, fusion reactions predominately occur in the moderately-strongly coupled. Understanding the charged particle stopping in this regime is critical to successfully designing and modeling burning plasma in these systems. The collision physics utilized in design codes is the foundation for ICF and stellar evolution predictions.

Few plasma stopping power measurements (in any regime) have been published to date. The lack of data stems from the difficulty of producing relatively large volumes of plasma (at high density and temperature) while simultaneously making a well-characterized charged particle source.

We have embarked on an ambitious campaign to experimentally test stopping power models. The technique utilizes two short-pulse laser generated proton beams. One beam is used for isochoric heating of solid density matter while the second is used to probe the heated matter. The experiment will be compared to current stopping power models and the molecular dynamics code ddcMD. The measurement and comparison will serve as a bench mark and help further the understanding of energy exchange in ICF and astrophysics models.

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Laser-like x-ray sources based on optical reflection from relativistic electron mirror

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A novel scheme is proposed to generate uniform relativistic electron layers for coherent Thomson backscattering[1]. A few-cycle laser pulse is used to produce the electron layer from an ultra-thin solid foil. The key element of the new scheme is an additional foil that reflects the drive laser pulse, but lets the electrons pass almost unperturbed. It is shown by analytic theory and by 2D-PIC simulation that the electrons, after interacting with both drive and reflected laser pulse, form a very uniform flyer freely cruising with high relativistic gamma-factor exactly in drive laser direction (no transverse momentum). It backscatters probe light with a full Doppler shift factor of 4*gamma^2. The reflectivity and its decay due to layer expansion are discussed.

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Improving beam spectral and spatial quality by double-foil target in laser ion acceleration*

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Mid-Z ion driven fast ignition inertial fusion[1] requires ion beams of 100s of MeV energy and < 10% energy spread. The Break Out Afterburner (BOA)[2] is one mechanism proposed to generate such beams, however the late stages of the BOA tend to produce too large of an energy spread. Here we show how use of a second target foil placed behind a nm-scale foil can substantially reduce the temperature of the co-moving electrons and improve the ion beam energy spread, leading to ion beams of energy 100s of MeV and 6% energy spread.

*This work conducted under the auspices of DOE by the Los Alamos National Security and the Los Alamos National Laboratory, and supported by LDRD. LA-UR-10-02234

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Integrated experiments of Fast Ignition with Gekko-XII and LFEX lasers

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Based on the successful result of fast heating of a shell target with a cone for heating beam injection [1], FIREX-1 project has been started from 2004. Its goal is to demonstrate fuel heating up to 5 keV by using upgraded heating laser beam. For this purpose, LFEX laser, which can deliver, at the full spec, an energy up to10 kJ in a 0.5-20 ps pulse, has been constructed beside Gekko-XII laser system at the Institute of Laser Engineering, Osaka University. It has been activated and became operational since 2009. Instead of the previous experiment with PW laser [2], upgraded integrated experiments of Fast Ignition have been performed by using LFEX laser. Initial experimental results including implosion of the shell target by Gekko-XII, heating of the imploded fuel core by LFEX laser injection, and enhancement of the neutron generation due to fast heating have been achieved. Results indicate that 5-keV heating can be expected at full output of LFEX laser with improved heating efficiency.

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Efficient one-to-one modeling of inhomogeneous plasmas*

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Novel laser systems with unprecedented energies are now coming online, with the National Ignition Facility and, in the near future, the HiPER project, reaching the extreme conditions required for many applications of interest such as laser fusion, laboratory astrophysics, or plasma-based ion acceleration. Numerical simulations play a crucial role in understanding the physics and optimizing the physical parameters and setup of these upscale experiments. However, the different spatial and temporal scales involved make these numerical experiments extremely demanding in terms of computational resources and multi-dimensional full-scale simulations are not yet possible to accomplish.

Following the work on a optimized hybrid algorithm for modeling inhomogeneous plasmas by B. Cohen *et al.*[1], an hybrid algorithm was implemented in OSIRIS 2.0[2] allowing for the self-consistent modeling of all the relevant physics at different scales, and leading to a dramatic change in the computational resources required to model laser-solid interactions.

The possibility of performing for the first time full-scale one-to-one modeling of fast ignition and ion acceleration in solid foils will be demonstrated, and the critical issues of laser absorption, beam energy/divergence, magnetic field generation, and energy deposition will be addressed in a fully self-consistent manner. Our results provide an integrated physical picture and clear directions for future experiments.

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Production and Applications of Dense Laser Pair Plasmas *

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This paper reviews recent developments in the production of electron-positron pair plasmas produced by ultra-intense lasers. Building on recent experiments from the Titan and Omega-EP lasers, we use the CERN code GEANT4 plus PIC codes to simulate pair production from gold targets irradiated by ultra-intense lasers. Pair yield scaling study results will be presented. Potential applications of such dense pair plasmas to both astrophysics and dense positronium physics will also be discussed.

*This work partially supported by DOE DE-SC0001481 and NSF AST-0909167

Multi-keV X-ray Yields from High-Z Gas Targets Fielded at the OMEGA Laser and the National Ignition Facility*

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We report on measurements and modeling of fluxes from X-ray source targets recently shot at the National Ignition Facility (NIF) and at the Omega laser. The targets were thin-walled pipes filled with mixtures of Xe and Ar gas at pressures of 1 to 1.5 atmospheres. The targets were irradiated with 3ω laser light, 20 kJ in 1 ns at Omega and 350 kJ in 5 ns at NIF. The emitted X-ray flux was monitored with multiple channels of X-ray-diode based DANTE instruments, and imaged with gated X-ray detectors. We compare predicted X-ray yields to measure yields. The current modeling appears to under-predict the yield of gas mixtures containing Ar.

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Transport properties of Low-Z mixtures*

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Mixtures of helium and hydrogen at high pressures and temperatures are major components of jovian planets. For neptunian planets, the properties of mixtures of water, methane and ammonia are of considerable importance to the understanding of the planetary interiors. The pressures and temperatures in the deep interiors of these giant planets can reach several Mbar and several thousand Kelvins. Using quantum molecular dynamics, we explore the properties of these mixtures at planetary conditions. In particular we discuss the electrical conductivity and reflectivity at high pressure and high temperature of those mixtures in comparison to pure hydrogen and pure water respectively.

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Kinetic Theory Molecular Dynamics[a]

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Hot dense radiative (HDR) plasmas common to Inertial Confinement Fusion (ICF) and stellar interiors have high temperature (a few hundred eV to tens of keV), high density (tens to hundreds of g/cc) and high pressure (hundreds of Megabars to thousands of Gigabars). Typically, these plasmas are described by short distance quantum mechanical effects such as diffraction and long distance classical collective effects. Modeling the non-equilibrium properties of these plasmas with classical molecular dynamics using statistical potentials continues to be a challenge. The statistical potentials are derived for equilibrium situations and their applicability to non-equilibrium processes is suspect. By considering a suggestion made by Murillo that classical MD for ions could be married to quantum kinetic theory for electrons, we show how such an approach arises from the Wigner quantum Liouville equation. A coupled set of equations describing the classical motion of ions coupled to a quantum electron fluid along with a kinetic equation for the electron fluid is derived. This approach offers the potential of modeling hot dense plasmas on the ion time scale and hence allows molecular dynamic modeling of thermonuclear burn.

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Wednesday, June 16, 2010

Fast Ignition (I)

Session Chair: B. Albright, LANL

K. Shigemori, ILE (Invited)
Y. Gu, CAEP
J.C. Fernandez, LANL
D. Jung, LANL
P. Michel, LLNL

UNM LOS ALAMOS

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Earth and planetary science study with Gekko-XII-HIPER laser facility at ILE, Osaka University

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-High pressure experiments

We have been developing the experiments on high-pressure EOS (equation of state) for materials which are of great interest in earth and planetary sciences. The main component of the Earth's core is iron. Our laser facility can easily access the Earth' core condition (~350 GPa, 6000K). We have measured the sound velocity of the shock compressed iron up to 700 GPa in liquid phase with side-on x-ray radiography. We also measured the shock Hugoniot for hydrogen (H_2), which is also important material in Jupiter. High precision data were obtained up to 55 GPa.

-Impact experiments

The impact velocities of asteroids on Earth and other terrestrial planets can be greater than 10 km/s, and impacts at these high velocities can produce significant effects on the planetary surfaces. However, since macroscopic (~ 0.1 mm) projectiles with an aspect ratio of ~ 1 are not easily accelerated to more than 10 km/s in laboratories, there are few detailed experimental studies. In this paper, we demonstrate that impact velocities greater than 10 km/s can be achieved with glass and aluminum projectiles of 0.1–0.3 mm in diameter on the GEKKO XII-HIPER laser. The velocity of the projectiles is estimated based on the images taken by high-speed X-ray streak and framing cameras. We also demonstrated experiments on creater generation, and dust recovery.

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Fast ignition researches at LFRC*

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Abstract: Some progress on fast ignition research at LFRC was reported. Indirective driven Cone-shell targets compressed experiments were conducted at Shenguang series laser facility. Clear framing self-emitting and backlighting images of core were observed in cone-shell target compressed experiments. The areal density variation curve versus time is got and the highest areal density achieve 5.8mg/cm2. It was found that the aeral density and stability of core were affected by the symmetry of cone-shell assembly. Hot electron transport in CH and metal targets was researched with CTR. The range of hot electrons in CH material is shorter than that in metal material, which indicates conductivity is important in hot electron transport. And the main energy deposition mechanism of hot electrons in low density area is ohm heating.

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Fast Ignition with Laser-Driven Ion Beams*

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We report on the US research program on fusion fast ignition[1] using laser-driven ion beams[2-3]. Compressed DT fuel can be ignited with beams of carbon ions (energy ~ 500 MeV) with a sufficiently quasi-monoenergetic energy distribution (energy spread ~ 10%)[4]. It is also possible to ignite with proton beams[5], although that method is not discussed in this presentation. Mechanisms that enable a short-pulse laser to drive the ignitor ion beam are summarized[2-7], especially ~ GeV ion energies[6-7]. The present aims of our ion-acceleration program are to reduce the C-ion energy spread for energies in the range 0.1 – 1 GeV, and to improve the conversion efficiency of the laser energy into the ion beam. In this presentation, we summarize the ignition calculations and requirements, the latest 1, 2 and 3 dimensional simulations that guide our experimental work at the Los Alamos Trident laser facility, and the experimental progress to date.

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New ion acceleration mechanisms in relativistic laser-nanotarget interactions*

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An ultrahigh-intensity laser interacting with matter accelerates electrons nearly to the speed of light. These in turn can be used to accelerate protons and heavier ions. Since electromagnetic fields in laser plasmas can be more than a million times stronger than in conventional accelerators, lasers have the potential to shrink accelerators from kilometer-sized to room-sized facilities, suitable for universities, industry and hospitals. However, the ion energy based on conventional acceleration mechanisms[1] seems to have saturated, remaining too low for most advanced applications. Herein is the first experimental demonstration of a new acceleration regime, with much higher performance, called Break-Out Afterburner acceleration [2,3]. Utilizing the ultrahigh pulse contrast at ultrahigh power at the LANL Trident laser, and nm-thick diamond targets, the energy of the laser-accelerated carbon ions increases by an order of magnitude up to 0.55GeV (45MeV/Nucleon), relevant to a wide array of applications, ranging from fusion energy production[4] to medicine and tumor therapy. Through the polarization of the laser pulse the energy spectrum of the accelerated ions can be manipulated to alter the exponential decaying spectrum to a more quasi-monoenergetic spectrum, necessary for most applications utilizing ion beams. The conversion efficiency of the experimentally obtained quasi-monoenergetic carbon C^{6+} spectra is one order of magnitude higher than prevously reported[5].

*This work conducted under the auspices of the LANL Laboratory Directed Research & Development (LDRD), the DOE Office of Fusion Energy Sciences (OFES), and by the Deutsche Forschungsgemeinschaft (DFG) through Transregio SFB TR18, the DFG Cluster of Excellence Munich-Centre for Advanced Photonics (MAP) and DFG LMU-Excellence (M. Hegelich).

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Towards a better understanding of Laser Plasma Interaction on the National Ignition Campaign*

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The "Hohlraum Energetics" experimental campaign on the National Ignition Facility has demonstrated a symmetric capsule implosion and radiation temperatures appropriate for ignition conditions[1]. Symmetry was achieved by controlling the energy transfer between cones of laser beams at the laser entrance holes of the hohlraums.
In this presentation, we will revisit the analysis of laser plasma interaction (LPI) in these experiments and link these processes to the hohlraum energetics. We are analyzing LPI by measuring: i) the energy transfer between cones of beams, measured by the SXI (static x-ray) diagnostic; ii) the backscatter, measured by FABS/NBI (full aperture backscatter station/near backscatter imager); iii) the hot electrons production, measured by FFLEX. The LPI analysis provided by these measurements is then correlated with the x-ray drive of the hohlraum (measured by Dante) and the implosion symmetry, measured by GXD (gated x-ray diagnostic). Calculations using our LPI and hydrodynamic codes are used to provide further insights on the processes taking place in the hohlraum.
This global analysis provides a connection between the measured crossed-beam transfer, backscatter, symmetry and drive; it reconciles the LPI measurements with the hohlraum energetics.

* This work was performed under the auspices of the U.S. DOE by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344 and by Los Alamos National Laboratory under contract DE-AC52-06NA25396.

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Wednesday, June 16, 2010

Fast Ignition (II)

Session Chair: J. Fernandez, LANL

S.R. Nagel, Imperial College
D.J. Strozzi, LLNL
D. Ho, LLNL
C. Ren, LLE
J.O. Kane, LLNL

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Control of Relativistic Electron Generation in High-Intensity Laser-Solid Interactions

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With applications in the generation of energetic particle beams, radiation sources and as drivers for igniting fusion capsules, it is vital to enhance the understanding of how relativistic electrons from laser-solid interactions are created and what mechanisms influence them. We investigate how energy is absorbed by the material and converted into these energetic electrons. This is achieved through studies of relativistic electrons escaping the rear surface of a solid irradiated at normal incidence by a laser with intensity in excess of 10^{19} Wcm^{-2}.

We will discuss ways to control the temperature of the relativistic electrons escaping the target by varying experimental parameters such as laser polarization, target thickness and laser contrast. For example, we observe an effective temperature enhancement with increasing target thickness and for linear laser polarization. Results from the experiment are also compared to OSIRIS PIC simulations.

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Modeling of Electron-Driven Fast Ignition at Ignition Scale*

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We are performing electron-beam transport simulations with the LSP code[1] to determine the ignition requirements for cone-guided fast ignition (details of our method and early results are in Ref. 2). We run LSP as a direct-implicit electromagnetic PIC code, with a fully kinetic treatment of the beam electrons and an Eulerian fluid treatment of the dense background plasma. We use idealized plasma conditions for dense (~ 300 g/cm^3) DT fuel with a carbon or other low- to mid-Z cone. We do not include a laser, but excite an electron beam in the cone with a distribution based on explicit-PIC calculations with the PSC code[3] of the short-pulse laser-plasma interaction. These simulations show the electron source is well-fitted by a two-temperature energy spectrum, and with a relatively large angular divergence. This second fact pushes us toward ignition hot spots whose radial width exceeds their lateral depth[4], and larger beam energies. We employ the Lee-More-Desjarlais[5,6] model for resistivity and other transport coefficients (recently corrected in LSP), and the fast electron stopping and scattering formulas of A. Solodov[7] and J. R. Davies[8]. In particular, the role of short-pulse laser characteristics (1054 nm wavelength light with pre-formed plasma inside the cone vs. 527 nm light without pre-plasma), magnetic-field focusing by resistivity tailoring, and cone-fuel standoff distance are explored. We are working to generalize these burn-free calculations to include fusion reactions.

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Indirect-Drive Fast-Ignition Capsule Designs*

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Reactor-scale fast-ignition capsule designs, that give overall energy gain above 150, will be presented. One-dimensional LASNEX calculations will show designs with different shock sequences, stability behavior, burn efficiency, and the required amount of dopant to block the laser-driven M-band radiation from reaching the cone (for the guiding of the ignitor beam) at the center of the capsule. Two-dimensional LASNEX simulations with the inclusion of ignitor beam allow us to explore the minimum required beam energy for ignition in terms of beam diameter, beam divergence angle, and beam temperature.

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Laser Channeling and Hosing in Millimeter-Scale Underdense Plasmas for Fast Ignition

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J.Tonge, W.B.Mori, University of California, Los Angeles

A key issue for the fast ignition concept is to deposit the ignition pulse sufficiently close to the compressed fuel core without significant energy loss in the mm-long underdense plasma surrounding it. One proposed technique is to use a channeling pulse to produce a low-density channel to reduce the nonlinear interactions of the ignition pulse in the underdense region. Recent 2D and 3D PIC simulation results for laser channeling in mm-scale underdense plasmas showed that the channeling speed is close to the ponderomotive hole-boring speed. Based on this we can estimate that ~40 kJ of laser energy is needed to hole-bore to 100 n_c in 100 ps. Lower laser intensity can decrease the required laser energy but would increase the required time. The simulations also showed that laser hosing can cause channel bending and bifurcation. The observed hosing growth rate was found to be lower than linear theories that neglect dispersive effects. We will present some preliminary study of the dispersive effects on hosing growth in 2D and 3D.

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Modeling of the LIFE minichamber Xe theta pinch experiment*

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The LIFE minichamber experiment is being designed to investigate cooling of the Xe buffer gas protecting the LIFE chamber wall. The state of the Xe after each LIFE fusion capsule implosion potentially affects the success of the next implosion, since it determines the environment into which the the next fusion target is being inserted (at a 13 Hz repetition rate) and may affect the propagation of the laser drive beams on the subsequent shot. The atomic physics in the regime of the strongly radiating, cooling Xe — a few μg/cc and a few eV and colder, is not well understood; experimental data is needed. In the minichamber experiment, a magnetically driven theta pinch configuration will be used to inductively heat a few-cm long cylinder of Xe to several eV. Thomson scattering will be used to determine the electron temperature and ionization state of the cooling Xe. Beam propagation may also be addressed. The current paucity of atomic data for Xe in the buffer gas regime makes designing the experiment challenging.

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Modeling

Session Chair: J. Tonge, UCLA

P. Loiseau, CEA/DAM (Invited)

J.A. Hittinger, LLNL

R. Kirkpatrick, Research Applications, Corp.

A. Link, Ohio State University

A.B. Sefkow, SNL

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Ignition design for the laser mégajoule (LMJ) and laser-plasma instabilities mitigation

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The major goal of the Laser MegaJoule (LMJ) [J. Ebrardt et J. M. Chaput *J. Phys.: Conf. Ser.* **112**, 032005 (2008)], currently under construction in France, is to achieve fusion ignition and thermonuclear gain from a target driven with a laser. In the framework of the Inertial Confinement Fusion (ICF) program, the US National Ignition Facility is on the point of demonstrate such a goal. The full LMJ laser will be comprised of 240 beams grouped in 60 sets of 4 beams (quads) each. Besides, first attempts to achieve ignition will be undertaken as soon as the facility is 2/3 completed. In this intermediate configuration, the 40 quads are arranged in 4 cones at angles 33.2°, 49°, 131° and 146.8° with 10 quads per cones. The laser is able to deliver up to 1.2 MJ and 390 TW at peak power, at 0.351 μm. An ignition indirect drive target has been designed for the 2/3 LMJ step. It requires 0.9 MJ and 260 TW of laser energy and power, to achieve a 300 eV temperature in a rugby-shaped hohlraum and give a yield of about 20 MJ. The mitigation of laser plasma instabilities (LPI) is a critical issue in ignition target design. Based on both scaling laws and integrated simulations, we present a method for constraining a LMJ target design by mitigating LPI. The study focuses on the analysis of linear gain for Stimulated Raman (SRS) and Brillouin (SBS) Scattering. Enlarging the focal spot is obviously a way to reduce linear gains. We show that this reduction is non linear with the focal spot size. For relatively small focal spot area, linear gains are significantly reduced by enlarging the focal spot. But, there is no interest in too large focal spots, because of the necessary larger Laser Entrance Holes, which requires more laser energy. We show that this leads to the existence, for a given design, of a minimum value for linear gains.

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Two-dimensional Vlasov Simulation of Driven, Nonlinear Electron Plasma Waves*

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Kinetic simulation of plasmas has proven invaluable in understanding diverse plasma phenomena. Because of their efficient representation of phase space, Particle-In-Cell (PIC) methods are the dominant kinetic simulation approach, but for some problems, the statistical noise inherent in PIC approaches can mask important physical phenomena. In such cases, a competitive alternative is to use a continuum-equation discretization of the Vlasov-Maxwell system (or, with collisions, the Boltzmann-Maxwell system) that is noiseless, but that requires a mesh covering the full phase space. In the VALHALLA project at LLNL, we have been developing advanced, scalable algorithms for the continuum solution of Vlasov-Maxwell that differ from traditional approaches to continuum Vlasov methods. Specifically, we use nominally fourth-order temporal and spatial discretizations of the conservative form of the equations using a finite-volume representation suitable for adaptive mesh refinement and nonlinear oscillation control.[1] In the work presented here, continuum solution of the Vlasov-Maxwell system using these techniques is extended to two spatial dimensions and two velocity dimensions.

Extensive theoretical and 1D, 2D, and 3D simulation studies have shown that large-amplitude electron plasma waves (EPW) trap and accelerate electrons and support a variety of uniquely kinetic nonlinear effects. These effects can degrade the amplitude and coherence of the EPW and thereby contribute to the saturation of stimulated Raman scattering (SRS) of laser light by an EPW. We report Vlasov simulation studies of electrostatically driven electron plasma waves (EPW) with fixed ions. In 1D, we study the evolution of a driven EPW to a steady state that supports an undamped BGK-like, finite-amplitude wave with frequency reduced from the linear normal mode by an amount proportional to the trapping frequency.[2] For systems many wavelengths long, this wave is unstable to a trapped particle modulational instability (TPMI).[3,4] In 2D, we consider a driving potential with a transverse finite width, as motivated by the localized driving of plasma waves by SRS in light speckles. This localization introduces additional losses as the waves propagate transversely out of the driven region and the particles are only transiently trapped. We explore how the frequency and amplitude of the driven wave and its stability are affected by the transverse width of the driver and the boundary conditions on the fields and the distribution.

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e-PLAS electron transport modeling for laser-driven fusion*

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We describe recent improvements to the e-PLAS[1] implicit/hybrid simulation code, and outline new results from applications to: A) shock ignition, B) fast-ion generation, and C) Omega EP driven electron transport in wires. We touch upon the code's new variable Z capability, full field component additions, array-allocatable executable, and graphics access through the IDL Virtual Machine. The e-PLAS code tracks the laser as rays to critical, where it generates a prescribed hot electron emission, propagates this as either particles or a fluid across an Eulerian mesh, and then draws resistive fluid return currents by means of self-consistent *E*- and *B*-fields. Implicitness and Van Leer fluid modeling permit simulations with speed and economy on PC-class computers. A) Examining shock-driven ignition in a semi-1D configuration, we find, for example, that after 500 ps (requiring only 2 hours of 2.8 GHz CPU time) 35 keV electrons driven by a final 10^{16} W/cm^2 pulse couples sufficient energy to the cold background electrons and ions to launch a strong shock in hydrogen discernible in the net pressure profile. B) Alternatively, exploring the dynamics of a ~500 μm diameter, 50 μm thick, solid H_2 foil exposed to a 40 μm FWHM, $2x10^{19}$ W/cm^2 1 ps pulse, we calculate fast ions generated primarily forward at a peak density of 10^{18} $protons/cm^3$ and traveling 300 μm in 10 ps. By 6.9 ps front and backside thermoelectric B-fields of O(30 MG) are seen, and hot electrons spread laterally in the foil at 300 μm/ps, i.e. at c. C) Finally, application with fluid hot electrons to similar beam width, ps-long laser-driven transport at ~5 x 10^{18} W/cm^2 in gold capped copper wires shows both surface and body transport of the hot electrons, and low wire surface temperatures (≤ 10 eV) at even 13.3 ps. Particle hot modeling indicates more complex behavior, showing hot electron refluxing and possibly greater axial pinching of the hot electron flow.

*Supported in part by the USDOE under SBIR # DE-FG02-07ER84723, Program Manager: Dr. Francis Thio

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LSP modeling of the modification of escaping energetic electron spectra*

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Ultraintense laser interactions with solid density plasma involve significant transfer of energy to electrons at the critical density. The momentum distribution of these electrons plays a vital role in the Fast Ignition (FI) approach to Inertial Fusion Energy[1] and is essential to understanding laser interactions with critical or overdense plasmas. Electrons from intense laser plasma interactions are typically measured through their generation of secondary radiation or direct measurement of the electrons which escape the plasma. The direct measurement of escaping electrons using electron spectrometers would appear to be the more reliable technique however the electrons which leave the plasma to reach a detector are modified by electromagnetic fields in the material and at the plasma-vacuum interface as electrons leave a previously charge neutral plasma. To investigate the connection between the experimental measured electrons and the initial electron distribution, a number of particle-in-cell simulations were conducted.

LSP[2] simulations using a simulated electron spectrum based upon pondermotive scaling and measured laser to electron energy coupling are compared to experimentally observed electron spectra from the Titan laser at the Jupiter Laser facility. The simulated energy spectrum as recorded by an electron spectrometer is found to differ significantly from the spectrum computed within the target. Analysis of the numerical simulations suggest while the emitted electron energy spectrum is heavily influenced by the self-consistent electric fields as the electrons escape, the high energy component, electron energies greater than 4 MeV, of the electron spectrum contains information about the initial electron spectrum created in the laser plasma interaction and show only a modest 20-30% cooling with respect to the initial hot electron temperature.

* Work supported by the U.S. Department of Energy under contracts DE-FG02-05ER54834, DE-AC52-07NA27344 and by an allocation of computing time from the Ohio Supercomputer Center.

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Predictive capability for Z-Petawatt-driven high-energy K_α x-ray yields used to image HEDP experiments on the Z Machine*

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Initial experiments using the Z-Petawatt laser (ZPW) at high irradiance (up to 10^{20} W cm^{-2}) are underway, and a predictive capability for modeling the K_α x-ray radiation emitted by solid targets has been developed. ZPW will provide a high-energy (~10-80 keV), ultra-short-duration x-ray source for imaging HEDP experiments on the Z Machine. Crucial to the highest possible success of outstanding x-ray imaging performance is the attainment of significantly higher conversion efficiency ε of laser energy into high-energy K_α x-rays than is presently possible with the conventional direct irradiation of flat foils. We study novel target and imaging concepts aimed at dramatically increasing ε in order to enhance the quality of our experiments on Z. Presently, Sn (Z=50) foils are used to create ~25 keV K_α x-rays with ε up to a few 10^{-4} at best, and ε is not expected to improve for higher-energy K_α x-rays created by higher-Z targets. By first understanding the fundamental physics of optimizing K_α production in targets, through detailed comparisons between simulations and experiments, we expect to test novel target and imaging concepts designed to substantially increase ε, which, if realized, would be an outstanding benefit to ZPW on Z. Fully explicit and kinetic particle-in-cell simulations are employed to model the laser-target interaction self-consistently at solid density by injecting the electromagnetic laser fields from the boundary, not by prescribing an ad-hoc injection of an assumed electron distribution within a pre-formed blowoff plasma; there are no free numerical parameters in the simulations. Time-dependent high-energy K_α x-ray powers are passively computed from electron particle distributions and ITS electron-impact ionization cross section data. Recent direct-flat-foil ZPW experiments will be described that were executed in order to provide ε measurements for comparison to simulation predictions. The measured ε was correctly predicted within the experimental uncertainty, and so provides confidence for our established capability to predict high-energy x-ray yield in other, novel target arrangements for increasing conversion efficiencies. Quality and contrast improvements in high-energy x-ray imaging, whether from traditional or novel sources, are directly beneficial to HEDP experimental platforms such as Z and NIF.

*Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract No. DE-AC04-94AL85000. Support provided by the Laboratory Directed Research and Development Program at Sandia.

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F. Graziani, LLNL
M. Desjarlais, SNL
C. Fortmann, LLNL
J. Kress, LANL
G. Collins, LLNL

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Molecular Dynamics of Hot Dense Plasmas[a]

Presenter F. Graziani, V. Batista*, L. Benedict, J. Castor, H. Chen, S. Chen, J. Glosli, A. Graf, S. Hau-Riege, A. Hazi, S. Khairallah, L. Krauss, B. Langdon, R, London, A. Markmann*, M. Murillo**, D. Richards, R. Shepherd, L. Stanton, F. Streitz, M. Surh, H. Whitley, J. Weisheit
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Hot dense radiative (HDR) plasmas common to Inertial Confinement Fusion (ICF) and stellar interiors have high temperature (a few hundred eV to tens of keV), high density (tens to hundreds of g/cc) and high pressure (hundreds of Megabars to thousands of Gigabars). Typically, such plasmas undergo collisional, radiative, atomic and possibly thermonuclear processes. In order to describe HDR plasmas, computational physicists in ICF and astrophysics use atomic-scale microphysical models implemented in various simulation codes. Experimental validation of the models used to describe HDR plasmas are difficult to perform. Direct Numerical Simulation (DNS) of the many-body interactions of plasmas using molecular dynamics is a promising approach to model validation. We will discuss the development of a new combined simulation and experimental capability call Cimarron. The simulation capability is massively parallel and includes Coulomb interactions via statistical potentials, quantum mechanical emission and absorption of radiation and atomic kinetics. We present simulations results of electron ion coupling and charged particle stopping in hot and dense hydrogen (with and without high-Z dopants). The statistical potentials used in the molecular dynamics code are compared to path integral Monte Carlo and hypernetted chain methods. Results will be presented comparing the pair distribution functions for hot dense plasmas. The code is being validated with experiments at LCLS and the Jupiter Laser Facility in regimes accessible to both simulation and experiment. Simulation results of proton stopping in graphite target being shot at JLF will be shown. In addition, simulation results of planned experiments at LCLS to measure the dynamic structure factor will discussed. Finally, an approach dealing with the wide range of time scales in hot dense plasmas with burn will be proposed.

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

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XUV opacity of warm dense aluminum*

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The development of intense XUV free-electron lasers, such as the FLASH FEL in Hamburg, has stimulated renewed interest in measurements and calculations of the XUV absorption of warm dense matter[1,2]. Solid aluminum, with its plasmon energy at 15 eV and L edge at 73 eV provides a wide range of free-free dominated absorption that is well matched to XUV FELs and an excellent test of computational approaches to opacities of warm dense matter. Adding to the interest in aluminum is the systematic difference, on the order of a factor of two, between two widely referenced data sets for the absorption of aluminum in this energy range[3,4].

We present *ab initio* density functional calculations of the opacity of solid density aluminum for photon energies below 100 eV, both for ambient conditions and for temperatures up to 10 eV. These calculations transcend our earlier first-principles calculations[1], primarily through increased attention to the higher energy scattering properties of the *ab initio* atomic aluminum potential. For solid density aluminum at 300 K, we find absorptions that are in good quantitative agreement with the existing data sets and reproduce very well the qualitative absorption behavior up to the L edge. For warm dense matter conditions, these calculations corroborate our earlier prediction of a significant increase in absorption with increasing temperature[1], and compare well quantitatively, at the higher temperatures and energies, with the absorptions predicted using an *ad hoc* potential model[2].

*MPD is supported by Sandia, a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract No. DE-AC04-94AL85000.

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Dynamical structure factor for dense plasmas: Extended Born-Mermin theory and application to x-ray scattering for dense plasma diagnostics

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We present recent theoretical and experimental results for the dynamical structure factor (DSF) in dense laser produced plasmas. The DSF for applications in Thomson scattering experiments is calculated within the extended Mermin approach[1] going beyond the standard mean field random phase approximation. It incorporates dynamical electron-ion collisions as well as electron-electron local-field corrections. The Born-Mermin approximation is complemented by finite temperature density-functional molecular dynamics simulations for the static structure factors. Our approach allows to study systematically the impact of these many-particle effects on the dynamical response of strongly correlated plasmas, e.g. the inelastic x-ray scattering cross section. Our calculations are well supported by x-ray scattering data from dense plasmas over a large range of phase space parameters. Electron-ion collisional plasmon broadening is observed primarily in small-angle x-ray scattering from strongly coupled plasmas, allowing to measure the electrical and thermal conductivity. Electron-electron local field effects show up in degenerate plasmas, produced e.g. by shock-compression of solid targets[2]. In particular, a flat plasmon dispersion in the vicinity of the Fermi momentum is observed in agreement with our theoretical model. Since the dispersion is utilized to measure the free electron density, its *a priori* knowledge and understanding in high density plasmas is indispensable for successful x-ray scattering diagnostics e.g. in laboratory astrophysics experiments or ICF studies.

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Mixtures in the Warm, Dense Matter Regime*

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The bulk of normal matter from planets to the interface between the ablator and DT fuel in ICF targets to the intergalactic medium exists as a composite of various elemental constituents. The interactions among these different species determine the basic properties of such diverse environments. For dilute systems, simple gas laws serve well to describe the mixing. However, once the density and temperature increase, more sophisticated treatments of the electronic component and dynamics become necessary. For the warm, dense matter (WDM) region (10^{22}-10^{25} atoms/cm^3 and 300-10^6 K), quantum Monte Carlo and molecular dynamics, utilizing finite-temperature density functional theory (DFT), have served as the basic exploratory tools and benchmarks for other methods. The computational intensity of both methods, especially for mixtures, which require large sample sizes to attain statistical accuracy, has focused considerable attention on mixing prescriptions based on the properties of the pure atomic constituents. Though extensively utilized in many disciplines, these rules have received very little verification. We examine the validity of two such rules, density and pressure mixing, for LiH by comparing against quantum calculations for the fully-interacting composite system. We find considerable differences in some regimes, especially for optical properties. We also probe mass transport properties such as diffusion and viscosity. As a means of extending DFT results to higher temperature regimes, we also studied[2] the properties of LiH mixtures using orbital-free molecular dynamics (OFMD) approaches based on various approximations to the basic density functional. These OFMD schemes permit a smooth transition from the WDM region to simpler one-component plasma and ideal gas models· Finally, using the DFT-based techniques, we also examine the effects on the equation of state, opacity, and electrical and thermal conductivity of a metal impurity (Al) introduced into a poorly conducting mixture (polyethylene, CH_2).[3]

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Recreating Core States of Giant Planets, a new generation of condensed matter science*

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A breakthrough in exploring the behavior of materials at high compressions, to 1000-fold initial density, is underway thanks to experimental developments associated with achieving inertially confined fusion in the laboratory. The material states existing deep inside giant planets and brown dwarfs, and the hot-dense plasmas in stars like the Sun, are becoming accessible in the laboratory. Recent experiments show that at even a fraction of these compressions material behavior becomes somewhat exotic, with helium transforming to a metal at ~2 g/cc, fluid carbon being a polymeric metal up to 2 TPa (20 Mbar or 20 million atmospheres pressure), and diamond exhibiting remarkable strength when "isentropically" compressed to 800 GPa (8 Mbar). New diagnostics are determining lattice structure for solids, local ordering, complex boding, and transport at TPa conditions. Over the next couple of years, these capabilities will allow us to explore solids at >10 TPa, complex chemistry to 100 TPa (1 Gbar), and the nature of helium and hydrogen in the deep interiors of Jupiter and even super-giant exoplanets.

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Thursday, June 17, 2010

Plenary III

Session Chair: J. Kline, LANL

B. Hammel, LLNL

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Controlling and Diagnosing Hot-Spot Mix in NIF Implosion Experiments*

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Controlling the hydrodynamic growth of capsule perturbations is essential in the optimization of NIF ignition target designs. Mode numbers up to ~300 can have significant growth on the outer surface, and are important for assessing the impact of roughness of plastic (CH) capsules.[1] Although the rms surface finish of CH capsules is very smooth (~20 nm), high-mode "isolated defects" can occur on the final capsule from several sources, including: (1) localized bumps in the CH coating; (2) debris introduced during the assembly process (e.g. dust); (3) the fill hole and tube. According to simulations these seeds have the potential to grow enough during the acceleration phase to penetrate the imploding shell, producing a jet of ablator material (mass ~ 10's ng) which enters the hot-spot during deceleration. Although this amount of mix is tolerable, degradation in ignition capsule performance becomes significant at several times this amount.

Our predictions of hydrodynamic growth and resulting mix have a level of uncertainty that results from uncertainties in experimental conditions (e.g. drive spectrum), physical data (e.g. models for opacity and EOS), and the simulation method itself. It is therefore important to normalize the simulations through direct measurements of capsule performance (e.g. yield, ρR), and hot-spot mix, in actual NIF implosion experiments. By varying the simulated hydro growth through modifications in experimental design (e.g. peak x-ray drive), the *relative* simulated Growth Factors will enable us to more accurately set final surface finish requirements for ignition targets.

One method for inferring mix into the hot-spot is through the observed x-ray emission from the ablator material, since internal regions of the CH ablator are doped with Ge in nominal ignition designs. The hot-spot temperatures (~3 - 7 keV in pre-ignition targets) ionize the Ge to the K-shell, resulting in characteristic line emission. We have observed evidence of jets entering the hot-spot in early NIF implosion experiments through the measured x-ray spectra, and as "bright spots" in x-ray images, consistent with simulation predictions. Including a small amount of another high-Z material (e.g. Cu) in the innermost CH region (nominally undoped) would provide a unique indication of mixed mass from this region also, and a means of determining the dominant source of mix.

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

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Poster Session III
Rad-Hydro

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Quantitative Analysis of Structured Implosions Using a Combination of Different Wavelets, Curvelets and Geometric Measure Theory: From Target Surface Imperfections to Hydrodynamic Instabilities and Mix

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We will show how modern techniques of harmonic analysis can be applied to the study of multiscale structures in implosion radiographic images. From fine-scale texture-like features, to large scale correlated structures in predominantly radial or azimuthal directions, and by bypassing noise, our techniques can isolate these features and analyze them in aggregate form or individually. Morphological diversity extraction is the general banner under which many of these techniques operate. This involves finding the smallest number of largest coefficients in a certain redundant or overcomplete family of functions that can capture a certain morphological feature in phase space (scale and position space). Many refinements and tricks must be applied for best results. We will show how various techniques, when combined, will produce excellent separation of identifiable features in these images concentrating on two successive implosion radiographs from the Z machine at Sandia, for illustrative purposes.

WaSP functions or Wavelet Square Partition functions will also be applied to the original images as well as to separated and contrast enhanced portions of unwrapped (r, ϕ) Euclidean plane images which give quantitative new measures of how multifractal or multiscale a given image is. Comparison of Z1561 to Z1562 thus allows the quantitative analysis of complicated structures in X ray radiographic images of implosions. provided a sufficient number of scales is present in the image (typically 8 or more powers of 2).

We will also show how these techniques can be used to characterize target surface imperfections before any implosion has taken place (by the PSSDI technique, for instance) and how "near stochastic resonance," a physical model proposed a few years ago by the lead author, may explain how clustering of bumps on a target surface could give rise to very large seeds (compared to those asserted assuming randomly phased Fourier amplitudes) for the most hydro unstable modes with the largest growth factors. These ideas may have some bearing on current and future mysteries in NIF implosions.

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ICF Targets: Defect implosion experiments on Omega and NIF and characterization of copper doped beryllium capsules*

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Defect implosion ICF experiments on Omega and NIF require targets that have 1) a precisely machined defect trench around the equator of the capsule or 2) modulations machined into the capsule. Both types of targets must be able to retain pressurized DT gas without breaking. To form the defect trench, a trench of a particular width and depth is micromachined on the surface of a PAMS mandrel. The mandrel is then GDP coated and pyrolyzed to remove the PAMS mandrel and convert the GDP to CH. Limits on the trench dimensions are set by structural considerations. Additional requirements are set on aluminum deposition, gas permeation, and acceptable thickness and surface roughness at the trench. Defect implosion experiments can also use capsules with a modulated surface. These targets have bumps machined on the exterior of the mandrel and then coated with GDP. Gas retention and thickness uniformity also need to be considered when manufacturing these capsules. Capsule uniformity is a requirement to achieving ignition. Uniformity does not only refer to shape and surface roughness, but also to dopant concentration levels and spatial uniformity. Using confocal x-ray fluorescence (MXRF), the azimuthal variation of the copper dopant in sputtered capsule was determined. Since copper is well known to migrate spatially in electric circuits, the question was raised whether the act of pyrolyzing the plastic mandrel out of the capsule may also cause the copper to migrate. Our measurements show that the copper dopant varies as a function of azimuth by a few percent. Comparison of copper-dopant levels among shells made in the same sputter batch shows significant differences among the capsules.

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Investigations of Mix in Omega and NIF Capsules with an Eulerian Code*

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We have run simulations of ICF capsules using an Eulerian code with a turbulent mix model. We simulate two types of Omega capsules fielded in the Defect IMplosion Experiment (DIME). Both capsule designs have an outer radius of about 440 μm and have an 8.5 or 15 μm thick CH ablator. The previous simulations of Magelssen et al.[1] gave neutron yields that were too high by a factor of 40, but they did not use a turbulent mix model. Our 1-D calculations with a turbulent mix model predict yields that are only a factor of 8 too high. We are running 2-D simulations of thick and think ablator capsules with and without equatorial grooves machined into them. The grooves are about 18 μm wide and 2.5 μm deep. The experiments show a 50% reduction in neutron yield when a groove is present, which previous simulations without mix were not able to replicate. We will present results of these simulations and compare them to data. In addition, we are designing experiments for the National Ignition Facility (NIF) that will examine the behavior of feature-induced mix in a high neutron fluence environment. These data will be useful for better understanding the yield degradation of NIF ignition capsules due to mix. Our nominal capsule design has an outer radius of 1100 μm with a 15 μm thick CH ablator. They are driven by a 4 ns trapezoidal pulse using 350 kJ of energy. We have simulated grooves that are 5 μm deep with widths ranging from 10 μm to 80 μm. We find that the 80 μm wide groove produces the most informative x-ray images and still predict neutron yields of about 3 to 4 $\times 10^{13}$. Accurate prediction of the performance is important, since we need to balance having the neutron yield high enough to make those diagnostics useful without having the yield be so high that we compromise the x-ray diagnostics.

*This work conducted under the auspices of the U.S. Department of Energy under contract no. DE-AC52-06NA25396.

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Modeling direct-drive implosions using HYDRA*

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2D HYDRA[1] simulations of direct drive implosions of NIF capsules are presented. Directly driven implosions of target capsules at the NIF may provide a path to validating ICF modeling capability in the presence of high mode number features. One of the complications facing direct drive validation experiments, is the potential for spatial inhomogeneities in laser power deposition across the surface of the target to generate hydrodynamic instabilities that dominate the effects of imposed features. In order to make experimentally relevant predictions of direct drive implosion characteristics, laser beams modeled as a set of rays spaced over a super-Gaussian ellipse are utilized to create laser sources that match empirical phase plate data for the intensity distribution in the focal plane. Here, we study the effects of spatial inhomogeneity in the laser deposition across the surface of the target capsule on instability growth, neutron yield, implosion speed and implosion symmetry.

*This work conducted under the auspices of the US DOE.

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Applications of the HYDRA Detailed Configuration Accounting (DCA) Package*

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HYDRA[1] is a multi-physics, 2D/3D radiation hydrodynamics design code that is routinely used to simulate inertial confinement fusion (ICF) and high-energy density physics (HEDP) experiments. HYDRA's in-line NLTE atomic kinetics capabilities include an average-atom treatment (XSN[2]) and a newer super-configuration based treatment that incorporates the kinetics and screened hydrogenic models from CRETIN[3] (DCA). Recent updates to HYDRA-DCA include: physics improvements in the kinetics package/models, HYDRA support for NLTE equations of state, and support for mixed-cell advection. DCA provides the flexibility to evolve populations spanning more levels than modeled in XSN and to use externally generated models (energy levels, transition rates) of arbitrary complexity. HYDRA-DCA is being validated against tabulated opacities (LTE) and compared to XSN (NLTE) for ICF-relevant materials.

Results from test problems and HYDRA simulations of ICF and HEDP experiments will be presented to demonstrate the range of studies that have been enabled by the recent updates.

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Comparisons of simulated x-ray data to NIF experiments*

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The first experiments of the National Ignition Campaign occurred in the fall of 2009. X-ray data was collected by the Dante, SXI, and GXD detectors. This paper compares simulated x-ray data to the data recorded last fall. The x-ray data is simulated using temperatures, densities and opacities saved by HYDRA and Lasnex runs. The simulation process includes details of the spectral, spatial, and temporal response of the detectors. The Dante provides information about the temperature of the drive x-rays as a function of time. The SXI records a time integrated x-ray image that provides information about the spatial dependence of the laser energy reaching the hohlraum wall. The GXD records snapshot images of the hot gas at the center of the capsule near the time of peak compression. We will show examples of how changes in the Lasnex or HYDRA simulation can improve the agreement between simulated and experimental x-ray data. Our goal is to find a simulation that can match all three detectors.

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Experiments to Measure Ablative Richtmyer-Meshkov Growth of Gaussian Bumps in Plastic Capsules

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Growth of hydrodynamic instabilities at the interfaces of inertial confinement fusion capsules (ICF) due to ablator and fuel non-uniformities have been of primary concern to the ICF program since its inception. To achieve thermonuclear ignition at Megajoule class laser systems such as the NIF, targets must be designed for high implosion velocities, which requires higher in-flight aspect ratios (IFAR) and diminished shell stability[1]. Controlling capsule perturbations is thus of the utmost importance. Recent simulations have shown that features on the outer surface of an ICF capsule as small as 10 microns wide and 100's of nanometers tall such as bumps, divots, or even dust particles can profoundly impact capsule performance by leading to material jetting or mix into the hotspot. Recent x-ray images of implosions on the NIF may be evidence of such mixing. Unfortunately, our ability to accurately predict these effects is uncertain due to disagreement between equation of state (EOS) models. In light of this, we have begun a campaign to measure the growth of isolated defects (Gaussian bumps) due to ablative Richtmyer-Meshkov[2] in CH capsules to validate these models.

The platform that has been developed uses halfraums with radiation temperatures near 75 eV (Rev. 4 foot-level) driven by 15-20 beams from the Omega laser (Laboratory for Laser Energetics, University of Rochester, NY), which sends a ~2.5 Mbar shock into a planar CH foil. Gaussian-shaped bumps (20 microns wide, 4-7 microns tall) are deposited onto the ablation side of the target. On-axis radiography with a saran (Cl He_α - 2.8 keV) backlighter is used to measure bump evolution prior to shock breakout. Shock speed measurements will also be made with Omega's active shock breakout (ASBO) and streaked optical pyrometery (SOP) diagnostics in conjunction with filtered x-ray photodiode arrays (DANTE) to determine drive conditions in the target. These data will be used to discriminate between EOS models so that one may be selected to design the shape and intensity of the foot in an ignition-level drive pulse so that bump amplitude is minimized by the time the shell begins to accelerate.

*This work conducted under the auspices of US DOE campaign 10 (Inertial Confinement Fusion, Steve Batha program manager) and the National Ignition Campaign.

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Optimizing Direct-Drive Performance for Thin-Shell ICF Implosions on NIF*

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The National Ignition Facility will provide an unparalleled resource for investigating radiation-hydrodynamics within ICF environments. The Applications of Ignition (AoI) program currently underway at Los Alamos National Laboratory is designing a series of NIF experiments for analyzing the evolution of feature-driven shocks in the presence of TN burn. As part of the design process, the AoI team is investigating the viability of direct-drive configurations at NIF. However, because the NIF beam geometry is optimized for hohlraum targets, care must be taken to make the drive as symmetric as possible, to ensure that irregularities imposed by the drive do not overwhelm the intended experimental features. "Polar Direct Drive" (PDD) configurations for NIF have been proposed and analyzed in the past, but for the purpose of maximizing neutron yield[1]. We present results from an extension of the Cok et al. work aimed at minimizing the Legendre mode content imposed by a PDD configuration. This required multiparameter modeling of the empirical NIF phase-plate data within our Lagrangian radiation-hydrodynamic calculations. After the appropriate laser model had been applied, we conducted multidimensional parameter scans of our two- and three-dimensional calculations to find the optimal drive configuration for a thin-shell ICF capsule.

*This work is supported by US DOE/NNSA, performed at LANL, operated by LANS LLC under contract DE-AC52-06NA25396.

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Technique for measuring the zero-order hydrodynamics of a directly laser driven imploding thin-shelled capsule*

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Small capsule perturbations may impact our ability to achieve high yields on NIF. Diagnosing the hydrodynamic development and the effect of defects on burn will be difficult. Los Alamos is developing a program to better understand the hydrodynamics of defects and how they influence burn. One of the first steps in this process is to develop methods for measuring the zero-order hydrodynamics of an unperturbed thin-shelled capsule. These NIF capsules will be 1100 microns in radius with a CH shell thickness of 15 to 30 microns. An inner portion of the shell will be doped with Ge. The capsule will be filled with DT or a high-z gas. Our approach requires three separate experiments. The first experiments ignore the effects of mix. The inner 5 microns of the shell is doped with 1% Ge. The capsule is filled with Xenon such that the calculated imploded radius-time trajectory is the same as a 5 atmosphere filled DT capsule. Gating and streaking the implosion with a Ti backlighter make the capsule measurement. The second step is to replace the Xenon with 5 atmospheres of DT. In this experiment we attempt to determine the effects of mix on the gated profiles. Calculations suggest that above a certain amount of mix, the backlit gated radius-time trajectory broadens enough to be measureable. For this experiment the radius-time trajectory is measured by gating the implosion with an Sc backlighter. This experiment will give quality information about the amount of mix and its effect on the radius-time trajectory. The final experiment is designed to better understand the extent of the shell mix into the DT. The CH, DT filled capsule is again used. However, the 5-micron Ge layer is modified. A 1-2micron Ge doped layer is moved inward away from the CH-DT interface leaving 3 to 4 microns of pure CH. The new capsule radius-time trajectory is measured by again gating the implosion. A broadening of the capsule radius would be indicative of mix coming from the Ge doped region. Simulations of each of these experiments will be presented.

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The Effects of Radiation Transport on the Development of Instabilities in NIF capsules*

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Understanding and controlling hydrodynamic instabilities is critical to achieving ignition at National Ignition Facility (NIF). Small defects and other imperfections in the capsule shell can seed short wavelength instability growth at the ablation front and fuel/ablator interface. Depending on the amount of growth, small amounts of ablator mass can be injected into the hot spot and detrimentally affect ignition. High fidelity simulations of instability growth on NIF inertial confinement fusion (ICF) capsules are relied upon to set capsule specifications and optimize capsule design. Typically, radiation transport is approximated in most simulations with flux limited radiation diffusion. This approximation is used primarily due to its simplicity and fast computation despite known inaccuracies in regions that are optically thin or have large gradients in energy density[1]. Implicit Monte Carlo (IMC), conversely, treats the radiation transport of the photons exactly but cannot come close to simulating the total number of photons in the system. This leads to statistical noise and solutions that are limited in accuracy by the allowed computation time and available memory. Therefore, the effect of radiation transport approximations in simulations of instability growth in NIC ICF capsules should be an area of concern. Prior ICF capsule fill-tube experiments on Z have already showed that IMC radiation transport was necessary for high-fidelity simulations to match experimental radiographs.[2] In this paper, we examine the effects of radiation transport on the hydrodynamic evolution of perturbations, isolated features, and other capsule defects by comparing high-resolution IMC HYDRA calculations with those run with multi-group radiation diffusion. We will show when and where significant qualitative differences occur and discuss the physical reasons these differences present themselves.

* Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000

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40th Annual Anomalous Absorption Conference
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Gamma rays and the areal density of ICF capsules: Beyond the MIPS Model*

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We plan to use the Gamma Reaction History experiment[1] being built at the National Ignition Facility ("NIF")[2] to measure the time-dependent areal density of carbon in the ablators of plastic-shell ICF capsules. Such measurements of areal density will be important for assessing the quality of NIF implosions and their adequacy for the first ignition attempt, owing to the close relationship of areal density to fusion confinement time. The inference of areal density depends on the ratio of the flux of 4.44 MeV gamma rays emitted by ^{12}C nuclei in the ablator to the flux of fusion neutrons (from D+T reactions, for example) exciting the nuclear levels of ^{12}C. Our inference is typically based on a model for the capsule in which we assume that all neutrons travelling through the ablator are 14.1-MeV fusion neutrons from D+T reactions occurring in a point source at the centre of the capsule, that the ablator is a spherical annulus, and that the neutrons travel instantaneously from the site of their birth through all of the ablator material. We refer to this set of idealized assumptions as the Monoenergetic Instantaneous Point Source ("MIPS") model. The true situation is more complicated, however. In reality, neutrons are born over an extended volume, so their path length through the ablator is always greater than its radial thickness. Neutrons are downscattered as they transit the fusion fuel inside the ablator, and so do not have a monoenergetic spectrum. Other fusion reactions, for example T+T, produce a continuum spectrum superimposed on the downscattered D+T spectrum. The ablator may not be a spherical annulus, and may not be sharply distinct from the fuel volume, because of hydrodynamic instability and mixing. The emission of gamma rays is not isotropic in the centre-of-mass frame of the neutron and ^{12}C nucleus, and so may couple with possible asymmetry of the implosion to produce anisotropic capsule emission. Neutrons do not travel infinitely fast but require several ps to move through the capsule. To investigate the importance of these effects, we use detailed time-dependent radiation-hydrodynamic simulations of capsule implosions, incorporating transport of neutrons and charged particles. We report here on the development of correction factors that can be applied to a simple MIPS analysis, resulting in areal density inferences that account for these realistic, non-ideal effects.

*This work conducted under the auspices of US DOE/NNSA under Contract DE-AC52-06NA25396.

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Multiple Monochromatic Imager and Phase Contrast Imaging Diagnostics for Thin Shell Implosions on NIF*

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We are evaluating the utility of multiple monochromatic imager (MMI) and phase contrast imaging (PCI) diagnostics for proposed polar direct drive thin shell implosions on NIF, as part of LANL's Applications of Ignition effort. Using MMI, the primary goals will be to obtain time-resolved density and temperature profiles at various stages of the capsule implosion, and also possibly information about mix. We have performed atomic physics modeling of various candidate gas and metal dopants (Ar, Ti, Fe, Ge, and Kr) using PrismSpect to identify regions in ρ-T parameter space where emissivity ratios of H-like to He-like lines will allow us to deduce the electron temperature and density. We have also performed 1D and 2D simulations of imploding thin shell capsules with tracer particles placed at various initial radii to see where dopants might end up during an implosion. We are using the combination of these results to design dopant configurations, and we are also developing a "forward modeling" capability to generate synthetic MMI data in order to quantify the required diagnostic specifications. The PCI technique offers different diagnostic information from the implosion. PCI is a form of x-ray radiography with large object-to-detector distances, and has a demonstrated ability to detect sharp interfaces in a variety of objects ranging from biological samples to static NIF beryllium capsules with DT ice layers, to most recently, dynamic shocked plastic disks. These objects are typically relatively transparent to the x-ray probe, and information comes from the development of phase interference at a distance. The technique offers the ability to detect the edges of the imploding capsule as a function of time (given multiple radiographic images), and perhaps the location of the in-going gas shock. We are evaluating the ability to extract information of interest to our project by applying synthetic forward modeling to capsule implosion calculations. Requirements for the geometry (source-to-object and object-to-detector distances, and x-ray spot size) will be examined.

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Progress Towards a Radiation Hydrodynamics Code for Modern Computing Architectures LA-UR-10-02825

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Abstract

The delivery of the Roadrunner machine [1] at Los Alamos National Laboratory is evidence that a new era of large scale heterogeneous computing may be upon us. While there is by no means consensus that future machines will look anything like Roadrunner, there is overwhelming evidence that multi-core computing is now a reality [2]. All multi-core hardware paradigms, whether heterogeneous or homogeneous, be it the Cell processor, GPGPU, or multi-core x86, share a common trait in that data movement is the overwhelming bottleneck to scalable performance, as opposed to the speed of floating-point operations per processor. In multi-physics applications such as inertial confinement fusion or astrophysics, one may be solving multi-material hydrodynamics with tabular equation of state data lookups, radiation transport, nuclear reactions, and charged particle transport in a single time cycle. The algorithms are intensely data dependent, e.g., EOS, opacity, nuclear data, and multi-core hardware memory restrictions are forcing code developers to rethink code and algorithm design.

For the past two years LANL has been funding a small effort referred to as Multi-Physics on Multi-Core to explore ideas for code design as pertaining to inertial confinement fusion and astrophysics applications. The near term goals of this project are to have a multi-material radiation hydrodynamics capability, with tabular equation of state lookups, on cartesian and curvilinear block structured meshes. In the longer term we plan to add fully implicit multi-group radiation diffusion and material heat conduction, and block structured AMR. To date we have invested a large amount of effort in data layout, multi-layered communication paradigms, and general code infrastructure, and we are now starting in earnest to accelerate multi-material hydrodynamics algorithms. In this talk we report on strategies, successes, and failures in our development efforts, as well as plans for multi-physics coupling and next steps. We will focus in particular on the acceleration of multi-material hydrodynamics algorithms on Roadrunner.

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The effect of mix on symmetry capsule performance at NIF*

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LANL is interested in studying TN-burn using ICF capsule implosion experiments at NIF. However, the implosion dynamics and yield of a capsule can be greatly affected by the inclusion of shell material in the fuel through turbulent mix. Thus, we would like to use the BHR[1] model for mix to assess the performance of our capsules. Additionally, we would like to understand the implosion of symmetry capsules (*i.e.* symcaps) used by the National Ignition Campaign (NIC) to study hohlraum energetics[2] as a way to validate our capsule design methodologies for the Applications of Ignition project (AoI). The symcaps are designed to be surrogates for ignition targets that replace cryogenic fuel with the same mass of plastic, and initial experimental results indicate mixing of shell material in the central fuel region. The symcap targets are of interest to the AoI project since they have fuel conditions similar to the exploding pusher capsules used by AoI.

The BHR model is used for multi-material compressible turbulence, and uses a modified set of fluid equations that include transport of the turbulent quantities. It is used in conditions where hydrodynamic instabilities, *e.g.* Rayleigh-Taylor, have grown into fully developed turbulence. Two quantities are needed as initial inputs to this model the specific turbulence kinetic energy, K, and ε the dissipation rate for K. These quantities are typically chosen to empirically match measurement. A version of BHR has been implemented in a radiation-hydrodynamics code at LANL. All calculation presented will use 1-d Eulerian hydrodynamics and multi-group radiation diffusion, and will use a radiation drive determined from separate 2-d hohlraum calculations. We prefer this method because it allows us to model shocks without the use of numerical viscosity.

We will present our current progress in modeling the symcaps used by NIC, and the effect of the BHR model on capsule performance. We will also discuss how these results affect the AoI target design process.

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Generation of tens of GeV quasi-monoenergetic proton bunches with lasers at intensity $10^{21} \sim 10^{23}$ W/cm^2

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We present a scheme of proton acceleration from a moving double layer formed by an ultraintense circularly polarized laser pulse with intensity $10^{21} \sim 10^{23}$ W/cm^2 irradiated on a combination target. The target is composed of a thin overdense proton-rich foil located at the front and an underdense gas region followed behind[1]. When the areal density of the thin foil is small enough, the protons together with electrons in the thin overdense foil can be pre-accelerated under the laser irradiation[2]. Meanwhile the laser can partially transmit through the thin foil due to the relativistic-mass-increase induced transparency. As the laser pulse and the electron bunches from the thin foil pass through it and propagate in the ionized gas region, they excite high-amplitude electrostatic fields (or laser wakefields) moving at a high speed, which appear like a moving double layer. The pre-accelerated protons can be trapped and accelerated in the double layer, provided the laser intensity and plasma density are properly chosen, as demonstrated by particle-in-cell (PIC) simulations. Under the parameters used in our simulation such as the laser intensity of 10^{23} W/cm^2 and pulse duration of 75fs, the protons can be accelerated to the maximum energy of over 60 GeV with the energy spread less than 2% in 1D PIC simulations, as well as the maximum energy of 26 GeV with the energy spread less than 10% in 2D PIC simulations under different plasma parameters. With such a combination target, the trapped proton bunches can have a charge around nC, similar to proton acceleration from a pure thin-foil.

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INVESTIGATION OF ELECTRON HEAT CONDUCTION IN LASER PRODUCED EXPONENTIAL PLASMA DENSITY PROFILES

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In laser produced plasmas, steep density and temperature gradients make classical modeling of electron heat conduction difficult due to local variations in the electron mean free path. As a result, most radiation hydrodynamic simulations implement a flux limited diffusion model which selects the minimum between the classical Spitzer heat flux and some fractional limit times the free-streaming flux. While comparisons with experimental observations have provided guidance on the value of the flux limiter for various experimental configurations, there is always uncertainty especially when modeling new types of targets. In the work here, Collective Thomson scattering measurements of the spatial and temporal electron temperature profile resulting from a one micron laser incident on a preformed exponential density profile is presented. The spatial measurements straddle the critical surface for the 1 w light, and we observe heat conduction into both the over-dense and under-dense regions of the plasma. These measurements provide a proof-of-principle approach to performing well diagnosed experiments that can validate Fokker-Planck or analytic heat conduction models. The development of such models should provide a first principles approach to modeling heat conduction in radiation hydrodynamic codes replacing the current *ad hoc* method.

We wish to thank the Trident operations team for which these experiments would not have been possible. This work performed under the auspices of the U.S. Department of Energy by LANL under contract DE-AC52-06NA25396.

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Molecular Dynamic Studies of Particle Wake Potentials in Plasmas*

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Fast Ignition (FI) studies require a detailed understanding of electron scattering, stopping, and energy deposition in plasmas with variable values for the number of particles within a Debye sphere. Presently there is some disagreement in the literature[1,2,3] concerning the proper description of these three processes. These models assume electrostatic (Coulomb force) interactions between particles. Developing and validating proper descriptions requires studying the processes using first-principle electrostatic simulations. We are using the particle-particle particle-mesh (P^3M) code ddcMD to perform these simulations. As a starting point in our study, we examined the wake of a particle passing through a plasma. In this poster, we compare the wake observed in 3D simulations with that predicted by Vlasov theory. Comparisons with the electrostatic particle-in-cell (PIC) code BEPS are also in progress.

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Theory of superhot electron spectra generated by Raman scatter*

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In laser-plasma interaction (LPI) stimulated Raman scatter, electrons are accelerated by the electric field of the Langmuir decay wave, modifying the electron distribution function in the neighborhood of the phase velocity. Particle-in-cell (PIC) simulations of SRS in one or so laser speckles in ignition conditions produce a shoulder in the distribution function that falls off rapidly at higher energy. However experimentally the energy distribution has been fitted to Maxwellians extending far beyond $\frac{1}{2}m_e(\omega / k)^2$. Nature makes Maxwellian distributions by a succession of accelerations. However, passing an electron again through a similarly-oriented plasma wave seems unlikely to kick it above the trapping width unless the fast electron's direction is oblique to the plasma wave, so that $\mathrm{k} \cdot \mathrm{v} / k$ is brought within the trapping width. This deflection might be by electron-ion scattering or B fields.
We consider such reheating mechanisms in plasma conditions motivated by NIF ignition targets, using multidimensional (PIC) simulations and simpler models.

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Friday, June 18, 2010

Laser Plasma Interaction (III)

Session Chair: W. Kruer, LLNL

K. Flippo, LANL (Invited)

S. Finnegan, LANL

J.L. Martins, IST

R. Trines, Rutherford Application Laboratory

W. Seka, LLE

UNM LOS ALAMOS

Laser-Based Ion Beam Development for Dynamic Defects and Fast Ignition Fusion

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Laser-plasma accelerated ion beams are an emerging field with vast prospects, and promise many superior applications in a variety of fields such as cancer therapy, compact radioisotope generation, table-top nuclear physics, laboratory astrophysics, nuclear forensics, waste transmutation, and SNM detection. LANL is engaged in two specific applications that are the driving force behind our carbon ion beam development: ion fast ignition and dynamic capsule perturbation. A tertiary application, radiation oncology, in conjunction with our partners at FZD is another reason that is generating a lot of interest for developing high-energy, high-quality beams. Laser-to-ion beam conversion efficiencies of over 10% will be needed for practical applications, and we have already shown efficiencies of >5% from flat foils on Trident using just a 5^{th} of the intensity and energy of the Nova Petawatt. With structured curved cone targets, we have also been able to achieve major ion energy gains, leading to the highest energy laser-accelerated proton beams in the world. In addition to cone targets, we are developing heated hemispherical diamond focusing targets to produce focused carbon ion beams at Trident (80J at 1ps) and Omega EP (1000J at 10ps), where new diagnostics have been developed: the target heating laser (TVHL), a Thomson parabola ion analyzer (TPIE), and a new LiF based activation film pack (PFPII -LiFAP) for diagnosing the carbon beam spatial profile. 2-D and 3-D simulations of the Omega EP parameters, and the hemi-targets are revealing how to better construct and field these targets for integrated experiments next year, and promise to help make these applications a near term reality.

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Influence of binary Coulomb collisions on trapped particle nonlinearities related to the onset of stimulated Raman backscatter in the kinetic regime*

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The influence of binary Coulomb collisions on trapped particle nonlinearities related to the onset of stimulated Raman scatter (SRS) in a single laser speckle is examined using one dimensional VPIC[1], particle-in-cell simulations. Binary Coulomb collisions are incorporated using a numerical particle-pairing algorithm[2], which reproduces a collision integral of the Landau form.

Collisional velocity-space diffusion (detrapping) is found to have the largest effect on the onset of trapping-enhanced (i.e. kinetic) SRS, and leads to a temporal delay in the development of the first burst of kinetic SRS. It is shown that before the onset of electron trapping, SRS grows at the rate predicted by linear fluid theory and that, as particle trapping modifies the electron distribution function, the SRS growth rate increases, resulting in the rapid development of the first burst of kinetic SRS. When the collisional velocity space diffusion relaxation time is faster than the linear SRS growth time, the electron velocity distribution function remains Maxwellian and no inflation of SRS reflectivity is observed. The culmination of effects resulting from collisional detrapping leads to the reduction of SRS reflectivity from a single speckle of finite temporal and spatial extent (compared to the collisionless case), and increases the laser onset threshold for kinetic SRS inflation. Along with collisional diffusion, collisional absorption of the laser and SRS (inverse bremsstrahlung) is also observed. Collisional heating of the bulk electrons is shown to increase $k\lambda_{de}$, resulting in a reduction in the SRS reflectivity, consistent with previous VPIC simulations[3].

*This work conducted under the auspices of the US DOE.

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Radiation signatures of electromagnetic plasma microinstabilities with relativistic beams*

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The current filamentation instability is prevalent in scenarios associated with relativistic flows or relativistic beams in laboratory and astrophysical scenarios. Radiation signatures of this electromagnetic plasma microinstability, associated with the self-consistent dynamics of the electrons in the fields generated during the instability, are critical for the interpretation of astrophysical observations and to identify the current filamentation instability in experiments e.g. due to laser-generated relativistic flows in laser-solid scenarios or in fast ignition.

We explore the radiation signatures of the current filamentation instability using the OSIRIS 2.0 framework first in scenarios where the electromagnetic instability and the resulting fields arise from the crossing of plasma flows. We perform detailed 2D and 3D PIC simulations and focus our study on the electron time scale and on the radiation mechanisms associated with the dynamics of the electrons in the small-scale magnetic fields. The features of these radiation processes are explored using a post-processing radiation diagnostic that determines the power spectrum of the radiation using the particle's trajectory in phasespace (tracks).

The time resolved study of the radiation spectrum allows the correlation of its evolution with that of the instability. A steepening of the lower energy part of the spectrum is observed as the instability grows. This will be discussed and compared with the evolution of the fields (strength and characteristic scale), and for relativistic scenarios compared with synchrotron radiation theory. The role of plasma dispersion effects and their influence on the features of the lower energy part of the spectrum are also addressed.

This study is also generalized for conditions where the current filamentation instability is driven by relativistic beams. It is shown that clear radiation signatures can be identified, correlated with the key properties of the instability (growth rate and typical wavenumber of the instability) and the beam.

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Simulations of efficient Raman amplification into the Petawatt regime*

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The understanding of laser-matter interactions at petawatt intensities is a major goal of the Extreme Light Infrastructure (ELI) project. The architectures being considered for this facility are based upon solid state lasers which are very successful in providing petawatt peak powers to target. The breakdown threshold for optical components in these systems, however, demands meter-scale beams. For a number of years, Raman amplification, an approach mostly free of breakdown problems, has promised a breakthrough by the use of much smaller amplifying media, i.e. (millimetre diameter wide) plasmas, but to date, only 60 GW peak powers have been obtained in the laboratory, far short of the desired multi-petawatt regime. Here we show, through the first large scale multi-dimensional particle-in-cell simulations of this process, that multi-petawatt peak powers can be reached only in a narrow parameter window dictated by the growth of plasma instabilities. The control of these instabilities promises greatly reduced costs and complexity of intense lasers, allowing much greater access to higher intensity regimes for fundamental science and industrial applications. Furthermore, it is shown that this process scales to short wavelengths allowing compression of free electron laser pulses to attosecond duration.

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SBS, SRS, and TPD in planar target experiments relevant to direct-drive ICF *

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Planar-target experiments at the Laboratory for Laser Energetics have been carried out over the past decade to simulate conditions relevant to direct-drive ICF within the limits imposed by the 30-kJ UV OMEGA Laser System. The long-scale-length plasma is generally created by one or two sets of defocused laser beams followed by one or several more tightly focused interaction beams. The latter may or may not be smoothed by spectral dispersion and polarization smoothing. The pulse shapes generally varied from 1-ns square pulses to 0.5-ns ramps followed by 1-ns square pulses.

We recognize that, in most cases, the hydrodynamic evolution of the plasma during the interaction beams strongly influences the laser–plasma interaction (LPI) processes. On several occasions, we have observed cross-interactions between different LPI processes, some of which are of hydrodynamic origin. This is the case in particular for SBS, SRS, and TPD close to $n_c/4$ for a number of experiments. This will be discussed in detail in the presentation.

These LPI experiments have clearly shown the multibeam aspect of the TPD instability. The most recent analyses of similar SRS experiments indicate similar multibeam aspects, reducing SRS thresholds significantly.

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Friday, June 18, 2010

Laser Plasma Interaction (IV)

Session Chair: A. Schmitt, NRL

J. Myatt, LLE
H. Vu, UCSD
A. Maximov, LLE
R. Short, LLE
Z. Sheng, Jiao Tong University

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Calculations of preheat caused by the two-plasmon-decay instability in direct-drive ICF plasmas*

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The two-plasmon-decay instability is a potential source of target preheat in direct-drive-implosion experiments on OMEGA. A physical model of electron acceleration has been developed that relies on two-dimensional extended Zakharov calculations[1] of saturated two-plasmon-decay spectra. Hot-electron generation is computed via a test-particle approach. Hot-electron re-heating is identified as an important effect and is modeled by a particular form of boundary conditions on the test particles. Such boundary conditions might prove useful in other kinetic simulations of particle heating where re-circulation is a possibility.

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Hot-electron generation by the two-plasmon-decay instability in inhomogeneous plasmas*

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Hot electrons generated by the two-plasmon-decay (TPD) instability in plasmas with an experimentally relevant gradient scale length ($L_n \sim$ 130 μm) are studied using the RPIC code. The issue of electron recirculation is examined using two simplified models that represent two extreme limits: (1) complete absorption at the boundaries transverse to the laser-propagation direction (no recirculation) and (2) periodic particle-boundary conditions at the said boundaries. Spatially averaged electron-distribution functions indicate that the hot-electron temperature is dependant on the specific recirculation model. Langmuir wave (LW) and density k spectra show the initial daughter waves caused by TPD and the subsequent Langmuir decay instability (LDI) of the primary TPD-produced LW's. Two-dimensional spatial plots of the LW energy density and the background electron density indicate clear signatures of LW cavitation. Comparison is made with the extended Zakarov model predictions.

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Modeling of two-plasmon-decay instability in the plasmas of direct-drive inertial confinement fusion*

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In the plasmas of direct-drive inertial confinement fusion (ICF), the generation of fast electrons by the two-plasmon-decay (TPD) instability has been observed in experiments on the OMEGA Laser System[1] and in particle-in-cell simulations[2]. The TPD instability in these ICF experiments is driven by multiple crossing laser beams that are incoherent in space due to distributed phase plates and incoherent in time due to smoothing by spectral dispersion. In the linear instability regime, the convective and absolute modes of the TPD instability grow in the spectral domains determined by the angular structure of the crossing laser beams and the plasma density gradient in inhomogeneous plasmas.

It is shown that the saturation of the TPD instability is caused by the low-frequency plasma perturbations in the ion-acoustic spectral domain. These low-frequency perturbations are driven by the interaction of laser beams and by the interaction of plasma waves. The level of TPD saturation depends on the characteristics of the low-frequency perturbations.

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Anisotropy of collectively driven two-plasmon decay in direct-drive spherical irradiation geometry*

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Experimental observations of half-harmonic and hard x-ray emission on OMEGA have shown that TPD signals depend on the collective rather than the single-beam intensity[1]. The theoretical analysis of TPD in this situation is complicated, in that the instability is driven by several beams having a range of angles with respect to each other and to the density gradient of the spherical target. The resulting dependence of TPD plasma-wave amplitudes on these angles determines the anisotropy of the resulting hot-electron distribution, and so is important in modeling the preheat of the core by TPD-generated hot electrons[2,3]. Some general properties of the angular dependence of both convective and absolute TPD will be demonstrated and the consequences for hot-electron anisotropy discussed in this talk.

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On some nonlinear effects in laser absorption in plasmas

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Some nonlinear effects in inverse bremsstrahlung absorption and resonance absorption in plasmas have been re-investigated analytically and numerically. Based upon Fokker-Planck simulation, inverse bremsstrahlung (IB) absorption has been studied in a wide intensity range ($10^{12} \sim 10^{17}$ W/cm^2). It is found that the well-known Langdon's IB operator[1], which is usually valid when the electron quiver velocity is less than its thermal velocity, overestimates the absorption rate accompanying with an over-distorted non-Maxwellian electron distribution function (EDF) at high laser intensity. According to the small anisotropy of EDF in the oscillation frame, we introduce an IB operator[2], which self-consistently tackles the nonlinear effects of high laser intensity as well as non-Maxwellian EDF. Our operator is capable of treating IB absorption properly in the indirect and direct-drive inertial confinement fusion schemes with the NIF/LMJ laser parameters at focused laser intensity beyond 10^{15} W/cm^2.

Resonance absorption of a p-polarized laser pulse at the critical plasma density in a wide intensity range ($10^{14} \sim 10^{18}$ W/cm^2) is studied via particle-in-cell simulation[3]. As the laser intensity increases from the linear regime, the absorption rate first decreases due to relativistic modulation of the electron plasma oscillations excited at the critical density layer. However, the trend reverses after a critical intensity. The reversal can be attributed to the fact that the relativistic critical layer depends on the local intensity of the laser pulse, so that instead of occurring in a thin layer, resonance absorption occurs in a large plasma region, leading to absorption rate increase. The reflected-light spectrum also shows broadening and splitting of the harmonics at high laser intensities, which can be attributed to critical-surface oscillations driven by the laser ponderomotive force.

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