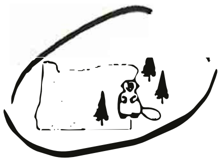

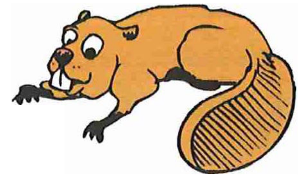

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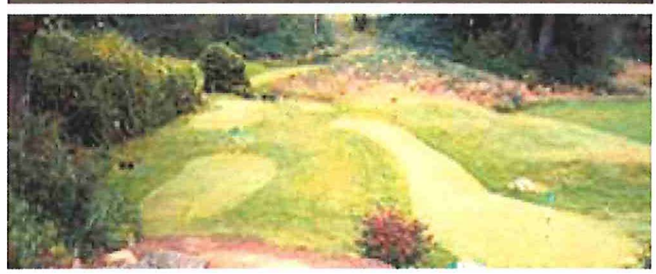

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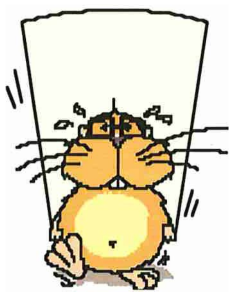

The crew…

Conference Organizer:	Hector Baldis
Conference Committee:	Denise Hinkel Bruce Langdon Bob Kauffman
Administrative Staff:	Estelle Miller Jamie Bozsik Colleen Camacho

PROGRAM – 34th Annual Anomalous Absorption Conference

SUNDAY	**6:00-8:00 P.M.**	**ANOMALOUS RECEPTION**	**GALLERY ROOM**	
MONDAY	**8:45 A.M. - 12:55 P.M.**	**ORAL SESSION 1**	**LONG HOUSE**	**W. B. MORI, CHAIR**
1O1	8:45 A.M.	Pesme, D.	Kinetic effects in the nonlinear evolution of a driven ion acoustic wave: Implications on stimulated Brillouin scattering	
1O2	9:05 A.M.	Loiseau, P.	Simulations of stimulated Brillouin scattering in large plasmas using the HERA platform	
1O3	9:25 A.M.	Niemann, C.	Observation of the two-ion decay instability with Thomson scattering	
1O4	9:45 A.M.	Froula, D. H.	Observation of the saturation of stimulated Brillouin scattering by ion-trapping induced frequency shifts	
1O5	10:05 A.M.	Divol, L.	A reduced model of kinetic effects related to the saturation of stimulated Brillouin scattering in long plasmas	
BREAK	10:25-10:55 A.M.			
1O6	10:55 A.M.	Moody, J. D.	Demonstration of backscattered SRS control from a 527 nm laser in a long scalelength high density laser plasma	
1O7	11:15 A.M.	Montgomery, D. S.	Observation of fluid and kinetic nonlinearities for Langmuir waves driven by stimulated Raman scattering	
1O8	11:35 A.M.	Kindel, J. M.	Qualitative comparison of Trident experiments using recent RPIC and PIC calculations	
1O9	11:55 A.M.	Dodd, E. S.	Quantitative verification of Reduced-Description Particle-in-Cell (RPIC) and full PIC Simulations for laser-plasma instabilities	
1O10	12:15 P.M.	Bezzerides, B.	Modeling stimulated Raman scattering (SRS) in the trapping regime: properties of a 3-wave, local space/time approach	
1O11	12:35 P.M.	DuBois, D. F.	Solitary-wave emission fronts, spectral chirping, and coupling to beam acoustic modes in RPIC simulations of SRS backscatter	
MONDAY	**7:30 - 8:30 P.M.**	**INVITED TALK 1**	**LONG HOUSE**	**A. B. LANGDON, CHAIR**
1IT		Lefebvre, E.	Particle acceleration from high-intensity laser- low-density plasma interactions	

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MONDAY	8:30 - 11:00 P.M.	POSTER SESSION 1	COUNCIL HOUSE
1P1		Edwards, M. J.	Prospects for using fill tubes for ignition targets on the NIF
1P2		Schmitt, A. J.	Growth of low-amplitude surface perturbations and laser imprint in directly irradiated targets
1P3		Cherfils-Clerouin, C.	Multimode weakly non linear Rayleigh-Taylor instability
1P4		Bates, J. W.	Simulations of laser-accelerated plastic targets with gold overcoats using the FAST code.
1P5		Mostovych, A. N.	Measurements of laser Imprint on CH and gold coated CH targets on the Omega laser facility
1P6		Metzler, N.	Laser driving and shaping pulse characteristics for hydro instability mitigation in ICF targets
1P7		Rygg, J. R.	Studying the burn region in ICF implosions with proton emission imaging
1P8		Langdon, A. B.	Spectra of scattered and emitted light in modeling of high intensity laser plasma interactions
1P9		Williams, E. A.	Laser plasma Interactions in NIF ICF target designs
1P10		Weber, S.	A NIF 3-D jet experiment
1P11		Rosen, M. D.	Analytic expressions for optimal hohlraum wall density and minimal wall loss
1P12		Goldman, S. R.	Calculations for NIF first quad gas-filled hohlraum experiments testing beryllium microstructure growth and laser plasma interaction physics
1P13		Mori, W. B.	Laser wakefield acceleration of auto-self-trapped electrons to ~1GeV in a plasma channel
1P14		Ren, C.	Energetic electron characteristics in fast ignition
1P15		Berger, R. L.	Creating uniform plasmas with short-pulse lasers by field and collisional ionization

1P16		Shepherd, R.	Short pulse lasers for the development of broadband x-ray sources
1P17		Kruer, W. L.	Laser plasma coupling with moderate Z, long scalelength underdense plasmas
1P18		Tsung, F. S.	Particle-in-cell simulations of the 2ωp instability
1P19		Keskinen, M. J.	Fast electron generation from the two-plasmon decay instability in long-scale-length plasmas
1P20		Johnston, T. W.	Vlasov-Maxwell SRS simulation for a parabolic density profile with injected seed light
TUESDAY	**8:45 A.M. - 12:55 P.M.**	**ORAL SESSION 2**	**LONG HOUSE** **J.M. KINDEL, CHAIR**
2O1	8:45 A.M.	Fernandez, J. C.	Laser-ablation treatment of short-pulse laser targets: towards an experimental program on energetic-ion Interactions with dense plasmas
2O2	9:05 A.M.	Hegelich, B. M.	Acceleration physics of laser-driven MeV-ion beams
2O3	9:25 A.M.	Albright, B. J.	Acceleration of fast ions with multiple charge states in short pulse laser experiments.
2O4	9:45 A.M.	Tikhonchuk, V. T.	Charge separation effects in solid targets and ion acceleration with two-temperature electron distributions
2O5	10:05 A.M.	Cooley, J. H.	3D simulations and modeling of the ionization scattering instability
BREAK	10:25-10:55 A.M.		
2O6	10:55 A.M.	Delettrez, J. A.	Transport of relativistic electrons for modeling fast ignition in the 2-D hydrocode DRACO
2O7	11:15 A.M.	Mason, R. J.	2-D implicit PIC/hybrid modeling of ultra-intense laser-matter interactions
2O8	11:35 A.M.	Myatt, J.	Hybrid Particle-in-Cell simulations of MeV electron transport in fast-ignition targets

2O9	11:55 A.M.	Ren, C.	Space charge effects in the filament instability of current beams in a plasma
2O10	12:15 P.M.	Eidmann, K.	Harmonic emission from the rear side of thin overdense foils irradiated with intense ultrashort laser pulses
2O11	12:35 P.M.	Wharton, K. B.	Evidence of spatially coherent synchrotron radiation from laser-plasma interactions
TUESDAY	**7:30 - 8:30 P.M.**	**INVITED TALK 1**	**LONG HOUSE** **R. L. KAUFFMAN, CHAIR**
2IT		Lee, R.	Plasma-related research on future FXELs
TUESDAY	**8:30 - 11:00 P.M.**	**POSTER SESSION 2**	**COUNCIL HOUSE**
2P1		Walsh, T.	Target fabrication and characterization for high energy density physics experiments.
2P2		Niemann, C.	Reduction of laser beam spray at 0.527 μm in an ignition scale length plasma with temporal beam smoothing
2P3		Velikovich, A. L.	Feedout-triggered instability of an expansion wave in an ideal gas with large γ
2P4		Li, C. K.	Effects of nonuniform illumination on implosion asymmetry in direct-drive inertial confinement fusion
2P5		Yin, L.	Trapping-induced coupling between Langmuir and beam acoustic modes: RPIC and full PIC simulations of stimulated Raman scattering
2P6		Savchenko, V.	Vlasov-Poisson and Vlasov-Maxwell simulations of laser-plasma Interactions using parallel codes
2P7		Tsung, F. S.	EM-PIC simulations of beat-wave excited electron acoustic modes
2P8		Lasinski, B. F.	Generation and transport of energetic particles in short-pulse high-intensity laser plasma interactions
2P9		Still, C. H.	Modeling of short pulse high intensity laser-plasma interactions in 2D & 3D PIC simulations
2P10		Winjum, B. J.	PIC simulations of laser-plasma interactions at intensities relevant to NIF

2P11		Fahlen, J.	Ion acceleration via ultra intense laser interactions with over and underdense plasmas
2P12		Ping, Y.	Demonstration of >100 times amplification of short laser pulses by Raman backscattering in plasma
2P13		Brantov, A. V.	Nonstationary effects in the nonlocal closure of transport equations
2P14		Johnston, T. W.	Plasma slab radiating pseudo-cavity mode in SRS-like behavior for frequency difference less than the plasma frequency: KEEN-type mode in relativistically hot plasma
2P15		Whitney, K. G.	Enhanced plasma collisionality, part II
2P16		Larroche, O.	An efficient explicit numerical scheme for hot fusion particle slowing-down in the Fokker-Planck formalism
2P17		Rygg, J. R.	A high-resolution neutron spectrometer for ρRfuel and Ti measurements at OMEGA and the NIF
2P18		Rozmus, W.	Self-organization of a plasma due to 3D evolution of the Weibel instability
2P19		Berger, R. L.	The frequency and damping of ion acoustic waves in semi-collisional, two-species plasma
2P20		Tikhonchuk, V. T.	Statistical model for laser beam multiple scattering on self-induced density fluctuations
WEDNESDAY	**8:45 A.M. - 12:55 P.M.**	**ORAL SESSION 3**	**LONG HOUSE** — **A. J. SCHMITT, CHAIR**
3O1	8:45 A.M.	Velikovich, A. L.	Transition from classical RM instability at embedded material interface to ablative RM and RT growth
3O2	9:05 A.M.	Aglitskiy, Y.	Observation of classical Richtmyer-Meshkov instability feeding ablative Rayleigh-Taylor growth in planar plastic targets
3O3	9:25 A.M.	Rygg, J. R.	An empirical dynamic mix model for ICF implosions
3O4	9:45 A.M.	Gunderson, M. A.	Utilizing emission spectroscopy to study the time dependence of interface mix

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3O5	10:05 A.M.	Anderson, K.	Simulations and experiments on adiabat shaping by relaxation
BREAK	10:25-10:55 A.M.		
3O6	10:55 A.M.	Craxton, R. S.	Polar-direct-drive experiments on OMEGA
3O7	11:15 A.M.	Meezan, N. B.	Detailed hydrodynamics simulations of 2ω laser-plasma interation experiments.
3O8	11:35 A.M.	Epstein, R.	Non-LTE speed of sound, irreversibility, and thermodynamic consistency
3O9	11:55 A.M.	Li, C. K.	Stopping and scattering of directed energetic electrons in high-temperature hydrogenic plasmas
3O10	12:15 P.M.	Clover M. R.	Developing a laser raytrace package in an Eulerian AMR radiation-hydrodynamics code (IAGO)
3O11	12:35 P.M.	Colombant, D.	Beam deposition model for energetic electron transport in inertial fusion

WEDNESDAY	**7:00 P.M. - 10:00 P.M.**	**BANQUET**	**CEDAR TREE ROOM**	**H. A. BALDIS, CHAIR**
THURSDAY	**8:45 A.M. - 12:55 P.M.**	**ORAL SESSION 4**	**LONG HOUSE**	**W. SEKA, CHAIR**

4O1	8:45 A.M.	Solodov, A. A.	Pump side-scattering in ultra-powerful backward Raman amplifiers
4O2	9:05 A.M.	Albritton, J. R.	Nonlocal electron transport
4O3	9:25 A.M.	Suter, L. J.	Controlling filamentation in 300eV 2ω (green) ignition target designs
4O4	9:45 A.M.	Schneider, M. B.	Experimental results on small-scale halfraums at the OMEGA laser
4O5	10:05 A.M.	Seka, W.	Scattered light measurements from spherical implosions on OMEGA

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BREAK	10:25-10:55 A.M.		
4O6	10:55 A.M.	Rousseaux, C.	Sub-ps Thomson scattering experiment: evidence of large spectral widths and atypical wavenumber spectra of driven IAW and EPW in short pulse interaction
4O7	11:15 A.M.	Afeyan B.	Optical mixing generation of KEEN waves, EPWs and their mutual interactions
4O8	11:35 A.M.	Manheimer, W.	1960's plasma physics looks at electron acoustic waves (EAW's) and kinetic electrostatic electron nonlinear waves (KEEN's)
4O9	11:55 A.M.	Rose, H. A.	Can a Langmuir wave's self-focusing beat its decay instability?
4O10	12:15 P.M.	Maximov, A. V.	Modeling of two-plasmon-decay instability in direct-drive ICF plasmas
4O11	12:35 P.M.	Short, R. W.	On the convective two-plasmon-decay instability in inhomogeneous plasmas
THURSDAY	**7:30 - 8:30 P.M.**	**INVITED TALK 4**	**LONG HOUSE** **D. E. HINKEL, CHAIR**
4IT		Johnston, T. W.	Plasma Physics at the Anomalous Absorption Conference, as seen by a plasma physicist newly returned to the fold
THURSDAY	**8:30 - 8:45 P.M.**	**BUSINESS MEETING**	**LONG HOUSE** **H. A. BALDIS, CHAIR**
THURSDAY	**8:45 - 11:00 P.M.**	**POSTER SESSION 4**	**COUNCIL HOUSE**
4P1		Weaver, J.	Spatially resolved, absolutely calibrated soft x-ray spectra at the Nike laser facility
4P2		Karasik, M.	Measurements of laser imprint on plastic and cryogenic foam targets
4P3		Gardner, J. H.	Spherical implosions using one sided illumination
4P4		Taccetti, J. M.	Richtmyer-Meshkov instability reshock experiments using laser-driven double-cylinder implosions

4P5	Delamater, N. D.	Calculations of double cylinder implosions at OMEGA
4P6	Zalesak, S. T.	Modeling the evolution of small-amplitude perturbations in converging spherical geometry
4P7	Kuranz, C. C.	Three-dimensional Rayleigh-Taylor instability in decelerating interface experiments
4P8	Casanova, M.	Target hydrodynamics for laser-plasma interaction studies
4P9	Serlin, V.	Development of the passive shock breakout diagnostic for the National Ignition Facility
4P10	Wharton, K. B.	Dirty secrets: laser prepulses and solid targets
4P11	Tzoufras, M.	The Weibel instability in fast ignition regimes
4P12	Hatchett, S. P.	Thoughts on return current transport through solid density, driven by ultra-high intensity laser/matter interaction
4P13	Dodd, E. S.	Investigation of fast-Ion production from short-pulse laser-matter Interactions
4P14	Lefebvre, E.	Kinetic modeling of stimulated Raman scattering in laser plasmas
4P15	Rozmus, W.	Non-equilibrium electron distribution functions and nonlinear thermal transport
4P16	Johnston, T. W.	A new plasma physics phenomenon: periodic kinetic electrostatic ion nonlinear (KEIN) waves
4P17	Strozzi, D. J.	Kinetic simulations of SRS saturation
4P18	Cohen, B. I.	Two-dimensional kinetic-ion simulation of stimulated Brillouin backscattering
4P19	Tikhonchuk, V. T.	Caviton formation and SBS saturation in high-intensity laser-plasma interactions

FRIDAY	8:45 A.M. - 12:55 P.M.		LONG HOUSE	W. ROZMUS, CHAIR
5O1	8:45 A.M.	Cobble, J. A.	Radiation drive with a composite laser pulse shape	
5O2	9:05 A.M.	Amendt, P.	Drive measurements in scale-3/4 hohlraums on Omega using the proton temporal diagnostic (PTD) : design and analysis	
5O3	9:25 A.M.	Jones, O. S.	Analysis of NIF-scale hohlraum drive symmetry experiments on Omega using point-projection radiography of thin shells	
5O4	9:45 A.M.	Evans, R. G.	Rapid heating of solid density material by the Vulcan petawatt laser	
5O5	10:05 A.M.	Gupta, A.	Interaction of intense short laser pulse with cluster plasma	
BREAK	10:25-10:55 A.M.			
5O6	10:55 A.M.	Glenzer, S. H.	Laser-plasma interaction experiments on the National Ignition Facility	
5O7	11:15 A.M.	Kirkwood, R. K.	Demonstration of a polarization dependent amplification produced by crossing beams in a flowing plasma	
5O8	11:35 A.M.	Langer, S.	Simulations of laser-plasma interaction experiments on NEL	
5O9	11:55 A.M.	Hinkel, D. E.	Laser coupling in reduced-scale targets	

Sunday, May 2, 2004

Daily Program

6:00 PM - 8:00 PM **Reception – Gallery Room**

Monday, May 3, 2004

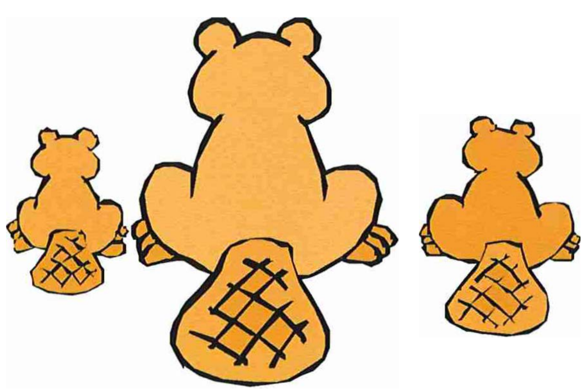
Daily Program

8:00 AM — 8:45 AM	**Continental Breakfast**
8:45 AM	**Conference Begins**
8:45 AM -10:25 AM	**Oral Session 1**
10:25 AM -10:55 AM	**Break**
10:55 AM —12:55 PM	**Oral Session 1 Cont**
7:30 PM -8:30 PM	**Invited Session**

Dr. E. Lefebvre

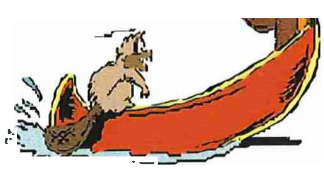
Particle acceleration from high-intensity laser-low-density plasma interactions

8:30 PM -11:00 PM	**Poster Session 1**



Oral Session 1

W.B. Mori, Chair



Kinetic Effects in the Nonlinear Evolution of a Driven Ion Acoustic Wave. Implications on Stimulated Brillouin Scattering

F. Detering, A. Heron, S. Hüller, D. Pesme, C. Riconda*, V. T. Tikhonchuk*

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* *Centre Lasers Intenses et Applications, Université Bordeaux 1, 33405 Talence, France*

The nonlinear evolution of an externally driven ion acoustic wave (IAW) is investigated by means of numerical simulations. We compare the results obtained (i) with a hybrid code, in which the electrons behave as a fluid and the ions are described along the particle-in-cell (PIC) method, and (ii) with a full PIC code, in which the kinetic effects on both species are retained. Various sets of parameters are considered, corresponding to cold or warm ions, weak or strong excitation. It is found that the electron kinetic effects play an important role. The interplay between kinetic effects and mode coupling effects result in a turbulent state characterized by a low fluctuation level, even in the strongly driven case. The implications of these results on Stimulated Brillouin Scattering are investigated.

Simulations of Stimulated Brillouin Scattering in large plasmas using the HERA platform

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In the context of the French LIL/LMJ construction, we are designing a new numerical tool aimed at studying the nonlinear evolution of Stimulated Brillouin Scattering (SBS) developing in large plasmas, of realistic size (mm size) and evolving on long time scales (hundreds of ps). Concerning the low frequency plasma response, we use a decomposition in which we separate the fluid variables into those varying on short spatial scales (SBS related) and those varying on long spatial scales (hydrodynamics related). The flow and density modification caused by the momentum deposition due to the backscattering of the incident laser wave is described in a self-consistent way. We describe the fundamental component of the ion acoustic wave excited by SBS, together with a few higher harmonics, and possibly a mesh of several subharmonics. We may also include, in the equations of evolution of these various IAW components, a nonlinear frequency shift modeling partial particle trapping effects. Thus, our code makes it possible to describe the SBS saturation mechanisms due to (i) the fluid IAW nonlinearity, (ii) detuning caused by the nonlinear frequency shift induced by partial particle trapping, and (iii) the subharmonic decay, potentially enhanced by the nonlinear frequency shift.

We use the HERA platform to solve the full set of fluid equations together with the paraxial equations describing the incident and scattered waves. We have added the equations describing the various IAW components in the limit where they are reduced to equations of paraxial type. This approximation is justified in the standard decay regime. Our new multi-dimensional parallelized laser plasma interaction code enables us to simulate the nonlinear behaviour of SBS in strongly inhomogeneous flowing plasma, such as an exploding foil. We tested its robustness in the extreme case of null IAW damping. We will present simulations describing SBS in an expanding plasma, in the regime of absolute instability, and we will demonstrate the need for taking into account the harmonics of the SBS generated fundamental IAW component.

Observation of the two-ion decay instability with Thomson scattering*

C. Niemann1, S.H. Glenzer[1], L. Divol[1], J. Knight[1], C. Constantin[1], D.H. Froula[1], G. Gregori[1], R.P. Johnson[2], D.S. Montgomery[2], E.A. Williams[1]

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The saturation of parametric instabilities, such as stimulated Brillouin scattering (SBS), plays a crucial role for the energy coupling of high intensity laser light into large-scale length plasmas. The SBS instability results from the resonant coupling of an intense laser pulse with an ion-acoustic wave to produce a light wave scattered back from the plasma. The two-ion decay of an ion acoustic wave into two daughter waves has been predicted theoretically as a saturation mechanism for SBS in high-Z plasmas.
We present a direct observation of the two-ion decay of ion-acoustic waves, driven in a gold-plasma by a high intensity interaction beam. The experiments were performed at the three-beam Trident laser facility. Au-foil targets were heated uniformly with a 200 J heater beam at 527 nm. A second high intensity interaction beam ($5 \cdot 10^{15}$ W/cm^2 at 527 nm) is used to drive ion-acoustic waves to large amplitudes. A third beam at 351 nm serves as a Thomson scattering probe. Using two separate Thomson scattering diagnostics with different scattering geometry simultaneously, we directly measure the scattering from thermal ion-acoustic fluctuations, the primary ion-acoustic waves that are driven to large amplitudes by the high intensity beam, and the secondary two-ion decay products. The decay products are shown to be only present where the interaction takes place and their k-spectrum is broad.

*This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-ENG-48.

Observation of the saturation of stimulated Brillouin scattering by ion-trapping induced frequency shifts

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We will report on recent experiments that measure the saturation of stimulated Brillouin scattering (SBS) by an ion-trapping induced frequency shift which was achieved using Thomson-scattering (TS) to directly measure the amplitude and the absolute frequency of the ion-acoustic wave ($2\mathbf{k}_o$) driven by the SBS instability. The use of two TS diagnostics allows us to directly measure the absolute frequency and amplitude of the ion-acoustic wave responsible for SBS. A frequency shift of up to 30% and simultaneous saturation of driven ion-acoustic waves and SBS reflectivity was observed. Furthermore, we have measured fast 30 ps oscillations of the SBS-driven ion-acoustic wave amplitude which is induced by the measured frequency shift. We will compare theoretical calculations and preliminary PIC and Pf3d simulation with the measured scaling between the frequency shift and the ion-acoustic wave amplitude.

These experiments used a three-beam configuration at the recently upgraded Janus Laser Facility at Lawrence Livermore National Laboratory. The He gas jet plasmas were well characterized using interferometry. A 600-psi backing pressure was used with a 1-mm cylindrical nozzle to create a peak electron density of $n_e=3\times10^{19}\mathrm{cm}^{-3}$. The plasmas where produced by a low intensity a low intensity ($3\times10^{13}\mathrm{W\text{-}cm}^{-2}$) heater beam with 325 J of 1ω ($\lambda = 1054$nm) laser light in a 1.2-ns-long square pulse. An 1.2-ns-long 1w interaction beam beam was used to drive the SBS process. The energy in the interaction beam was varied 10 J < E 135 J and focused through a continuous phase plate (CPP) producing a 250-micron diameter spot at the center of the plasma. The maximum intensity of the interaction beam was 2×10^{14} W-cm^{-2}. The third laser beam, 3 J of 2ω ($1_{2\omega}$=532 nm) laser light in a 2-ns square pulse, was used a a TS probe beam. The sound speed, low velocity, driven ion-acoustic wave amplitude and frequency where measured by imaging light scattered from the TS volume onto two separate streak cameras coupled to imaging spectrometers. spectrometers.

Using one of the TS diagnostics, the electron and ion temperature can be inferred; the ion temperature is determined by fitting the spectral width of the two ion-acoustic peaks, Ti=120±50 eV at 750 ps, while the electron temperature is given by the separation between the two peaks, Te=350±50 eV at 750 ps. These measurements compare well with three-dimensional hydrodynamic simulations that where done with the code HYDRA.

This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48 8

A reduced model of kinetic effects related to the saturation of Stimulated Brillouin Scattering in long plasmas

(oral preferred)

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We present a model for Stimulated Brillouin Scattering that consists of the classic 3-coupled-wave equations, where the equation for the driven acoustic wave includes a nonlinear frequency shift related to modifications of the ion distribution function by kinetic effects. This frequency shift is calculated in a quasilinear way from the locally averaged modifications of the ion distribution function, described in this model by a single parameter related to the width of the plateau. This parameter evolves according to an additional differential equation that describes the acceleration, advection and diffusion of ions around the phase velocity of the ion-acoustic wave. The behavior of this model will be discussed and compared to hybrid-particle-in-cell simulations performed with BZOHAR.

This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

34 th Annual Anomalous Absorption Conference
Gleneden Beach Oregon,
May 2-7, 2004

Demonstration of backscattered SRS control from a 527 nm laser in a long scale length high density laser plasma

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We demonstrate experimental contol of simulated Raman scattering (SRS) from a 527 nm interaction laser in a long scalelength high density plasma. Varying the probe laser intensity and laser smoothing by spectral dispersion (SSD) causes significant changes in the backscattering amplitude and spectra. The experiments combined with detailed simulations help develop a physics description of laser-plasma interaction at 527 nm. The interaction experiments were performed in a 2.5 mm plasma produced by laser-heating a gas-balloon target with 18 kJ of 351 nm light in a 1 ns pulse from 40 of the Omega laser beams. The resulting plasma has an electron density of about 13% critical for the 2w beam and an electron temperature of about 2 keV. Half-way through the 1 ns heating pulse the 2w and 3w beams begin interacting with the plasma and drive stimulated Raman backscattering (SRS), stimulated Brillouin backscattering (SBS), and filamentation for 1 ns. The interaction beam intensity ranges from about $1\text{x}10^{14}$ W/cm^2 to $1\text{x}10^{15}$ W/cm^2 and is always smoothed using a distributed phase plate. Increasing the probe intensity shows a rise in the 2w SRS to a plateau level and a broadening of the initially narrow SRS spectra. Detailed hydrodynamic simulations and paraxial wave calculations of the scattering constrained by the experimentally measured plasma parameters show that the scattering originates in two different plasma regions. One region has uniform plasma parameters and produces narrow SRS; the other region has a significant density gradient and produces spectrally broad SRS. Application of SSD reduces the broad SRS but does not significantly affect the narrow SRS. Inverse bemsstrahlung absorption of the incident laser light as well as the longer wavelength backscattered SRS light is important for interpreting the backscattering results. We will present a detailed description of the laser-plasma interaction based on experimental measurement and theoretical modeling.

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(Prefer Oral session)

Observation of Fluid and Kinetic Nonlinearities for Langmuir Waves Driven by Stimulated Raman Scattering*

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Thomson scattering was used to detect the Langmuir wave spectrum associated with stimulated Raman scattering (SRS) in experiments where the interaction beam is a diffraction-limited laser. On the scale of the intense focal region the background plasma conditions are extremely homogeneous, and allows detailed measurements of the Langmuir wave spectrum. The interaction laser drives SRS in a preformed CH plasma with $T_e \approx 500 - 700$ eV, and $n_e \approx 1 - 3 \times 10^{20}$ cm^{-3}. Langmuir waves with wave-number $k\lambda_D \approx 0.25 - 0.4$ are detected. At higher densities, multiple waves with discrete frequencies and wave-numbers are observed, consistent with Langmuir decay instability (LDI) cascade. At lower densities, a frequency-broadened wave is observed consistent with the nonlinear frequency shifts due to electron trapping. While this kinetic effect occurs to varying degree for all $k\lambda_D$ regimes, LDI cascade is observed to be limited to $k\lambda_D \leq 0.3$.

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Qualitative Comparison of Trident Experiments Using Recent RPIC and PIC Calculations

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Thomson scattering is used to measure plasma waves due to stimulated Raman scattering (SRS) on the Los Alamos Trident Laser[1]. RPIC simulations[2] have predicted a fluid-to-kinetic transition from saturation due to Langmuir decay instability (LDI) at small $k\lambda_D$ to saturation due to electron trapping at large $k\lambda_D$. Recent Trident experiments reveal such a transition.[3] Ongoing RPIC simulations, showing spectral detail that is associated with the nonlinear behavior of relevant stimulated scattering processes, also predict the fluid-to-kinetic transition to occur in upcoming gas-jet experiments on Trident. The upcoming gas-jet experiments offer the promise of qualitative comparison becoming quantitative by greatly reducing plasma flow and electron temperature during the experiment. RPIC suggests that a threshold to large SRS occurs when $k\lambda_D$ is held fixed and the incident laser intensity is varied. Trident experiments as well as multiple-speckle experiments on large lasers (e.g., NOVA) also suggest a threshold. We present results of simulations for fixed $k\lambda_D$ and theoretical scaling arguments that are qualitatively consistent with observed behavior.

[1] Montgomery, D. S., et al., "Recent Trident Single Hot spot Experiments: Evidence for Kinetic Effects, and Observation of Langmuir Decay Instability Cascade," Phys. Plasmas **9**, 2311 (2002)

[2] H.X. Vu, B. Bezzerides, and D.F. DuBois, "ASPEN: A Fully Kinetic, Reduced-Description Model for Simulating Parametric Instabilities," *J. Comput. Phys.* **156**, 12 (1999).

[3] Kline, J. L., Montgomery, D. S., et al., "Observation of a Transition from Fluid to Kinetic Nonlinearities for Langmuir Waves Driven by Stimulated Raman Backscatter," submitted to *Phys. Rev. Lett.* (2003).

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Quantitative Verification of Reduced-Description Particle-in-Cell (RPIC) and full PIC Simulations for Laser-Plasma Instabilities*

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RPIC is a reduced-description particle-in-cell code designed to investigate laser-plasma instabilities in physical systems with vastly different time scales prevalent under Inertial Confinement Fusion (ICF) conditions [1]. Such time scales include the laser, Langmuir, and ion acoustic time scales. In past literature, laser-plasma instability phenomena involving these disparate scales have mostly been studied with the extended Zakharov model. Recently, comparisons between the extended Zakharov model and the RPIC model were presented in a series of papers, Refs. [2-4], in which quantitative agreement between these two models are obtained in the fluid and quasi-linear regime. However, in the kinetic regime where electron and/or ion trapping is important, significant differences were found. In addition, the RPIC model itself has some limitations, such as, the frequency harmonics of Langmuir waves are neglected in arriving at the reduced model.

Our study has two parts. First, the convergence of solutions in RPIC is quantitatively assessed for the test case of Refs. 2-4 as the number of particles per cell is varied. The convergence of RPIC is compared to that of full PIC, thus showing the advantage of the former over the latter, in certain cases of interest for laser plasma instabilities. Second, it is expected that for sufficiently strong laser drives, RPIC may not capture laser-plasma instability physics accurately due to the lack of frequency harmonics in the Langmuir waves. Therefore, we would like to establish the regime of validity for RPIC, and to assess quantitatively if the physical regimes where RPIC fails are of interest to the conventional ICF indirect drive implosion scheme. Our current study is confined to one spatial dimension.

[1] H.X. Vu, B. Bezzerides, and D.F. DuBois, "ASPEN: A Fully Kinetic, Reduced-Description Model for Simulating Parametric Instabilities," *J. Comput. Phys.* **156**, 12 (1999).
[2] K.Y. Sanbonmatsu, H.X. Vu, D.F. DuBois, and B. Bezzerides, "A New Paradigm for the Self Consistent Modeling of Wave-Particle and Wave-Wave Interactions in the Saturation of Electromagnetically Driven Parametric Instabilities," *Phys. Rev. Lett.* **82**, 932 (1999).
[3] K.Y. Sanbonmatsu, H.X. Vu, B. Bezzerides, and D.F. DuBois," The Effect of Kinetic Processes on Langmuir Turbulence," *Phys. Plasmas.* **7**, 1723 (2000).
[4] K.Y. Sanbonmatsu, H.X. Vu, D.F. DuBois, and B. Bezzerides, "Quantitative Comparison of Reduced-Description Particle-in-Cell and Quasilinear-Zakharov Models Parametrically Excited Langmuir Turbulence," *Phys. Plasmas.* **7**, 2824 (2000).
* Supported under the U. S. Department of Energy by the University of California, Los Alamos National Laboratory under contract W-7405-END-76.

Modeling Stimulated Raman Scattering (SRS) in the Trapping Regime: Properties of a 3-Wave, Local Space/Time Approach.*

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Reduced model particle-in-cell code (RPIC) simulations have identified a regime of saturation of BSRS (high electron temperature and/or low density) where the Langmuir fluctuations show a narrow wavenumber spectrum.[1] This result provides the basis of a 3-wave model, coupling the Langmuir fluctuations, back scattered light, and incident laser beam. The Langmuir fluctuations result in nonlinear shifts in the damping, $\delta\gamma$, and frequency, $\delta\omega$, due to electron trapping.

In this talk we construct a 3-wave model for BSRS in a speckle with $\delta\gamma$, $\delta\omega$, given in terms of the local value of the Langmuir intensity, including a generalization to what was originally proposed in Ref. 2. Loss of electrons arising from motion transverse to the speckle leads to effects not included in Ref. 2. We use an analytical model for $\delta\gamma$, $\delta\omega$, consistent with the physical model originally proposed in Ref. 1 to account for the consequences of this side loss, an effect which is intrinsically multi- dimensional. We compare the results of this model to predictions of the RPIC code for the scaling of the time-averaged reflectivity with I_0, the incident light intensity, noting the limitations of the local space/time or adiabatic assumption. The scaling studies are performed with and without side loss. In these scaling studies we observe a sharp onset of large reflectivity over a narrow range of I_0. The physical basis for this onset is discussed, along with some speculations as to its importance for whole beam reflectivity.

1. H. X. Vu, D. F. DuBois, and B. Bezzerides, Phys. of Plasmas **9**, 1745 (2002).
2. G. J. Morales and T. M. O'Neil, Phys. Rev. Lett. **28**, 417 (1972).

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Solitary-wave emission fronts, spectral chirping, and coupling to beam acoustic modes in RPIC simulations of SRS backscatter*

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Detailed diagnostics of quasi-2D RPIC simulations of backward stimulated Raman scattering (BSRS), from single speckles under putative NIF conditions, reveal a complex spatio-temporal behavior. The scattered light consists of localized packets, tens of microns in width, traveling toward the laser at an appreciable fraction of the speed of light. Sub pico-second reflectivity pulses occur as these packets leave the system. The LW activity consists of a front traveling with the light packets with a wake of free LWs traveling in the laser direction. The parametric coupling occurs in the front where the scattered light and LW overlap and are strongest. As the light leaves the plasma the LW quickly decays liberating its trapped electrons. The high frequency part of the $|n_e(k,\omega)|^2$ spectrum, where n_e is the electron density fluctuation, consists of a narrow streak or straight line with a slope that is the velocity of the parametric front. The time dependence of $|n_e(k,t)|^2$, shows that during each pulse the most intense value of k also "chirps" to higher values, consistent with the k excursions seen in the $|n_e(k,\omega)|^2$ spectrum. But k does not always return, in the subsequent pulses, to the original parametrically matched value, indicating that, in spite of side loss, the electron distribution function does not return to its original Maxwellian form. Liberated pulses of hot electrons result in down-stream, bump on tail distributions that excite LWs and beam acoustic modes[1] deeper in the plasma. The frequency broadened spectra are consistent with Thomson scatter spectra observed in TRIDENT single-hot-spot experiments [2] in the high $k\lambda_D$, trapping regime. Further details including a comparison of results from full PIC simulations, and movies of the spatio-temporal behavior, will be given in the poster by L Yin *et al.*

[1] L.Yin *et al*, J. Geophys. Res., 103, 29,595 (1998)
[2] D. Montgomery *et al*, presentation at this conference.

*Supported by the USDOE

Invited Session 1

A. B. Langdon, Chair

34th[d] Annual Anomalous Absorption Conference
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Particle acceleration from high-intensity laser – low-density plasma interactions

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Plasmas can support very large electrostatic field, and hence appear as a most promising path towards compact particle accelerators. 200 MeV electrons are routinely produced with the "Salle Jaune" laser at Laboratoire d'Optique Appliquée, in experiments combining a mm-long helium gas jet and a 1 J, 30 fs light pulse. We will present 3D Particle-In-Cell simulations of these experiments that help understand the underlying physics: the laser light "adapts" itself, by self-focusing and steepening, into a compact light pulse which is then able to directly drive an electron plasma wave to wave-breaking amplitude – a maximum amplitude larger than 1 TV/m is calculated, and the accelerated electron distributions are in quantitative agreement with the experiments. The particles are accelerated as a narrow, collimated beam, with, e.g., 55±2 MeV electrons having a measured emittance of less than 3π mm.mrad, in agreement with calculations. Other simulations with slightly improved laser parameters suggest still better acceleration, coupling efficiency, and beam properties.

Ion acceleration directly by the laser is not efficient at these intensities, but can proceed through the acceleration of electrons. Electron motion driven by the laser pulse sets up quasistatic electric fields that can accelerate ions efficiently. The application of this mechanism to solid target has been abundantly studied, but its application to lower-density plasmas could also prove interesting, and will be considered. The variations of conversion efficiency, maximum ion energy, and ion beam collimation with interaction parameters will be examined.

Poster Session 1

Prospects for using fill tubes for ignition targets on the NIF *

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The notion of using a narrow bore fill pipe to charge an ignition capsule in-situ with DT fuel is very attractive because it eliminates the need for cryogenic transport of the target from the filling station to the target chamber, and in principle is one way of allowing any ablator material to be considered. A particularly attractive material for example is Be with a radially graded Cu dopant. This considerably reduces the growth of short wavelength perturbations, and should help reduce the impact of a fill tube on an implosion. Other prospects such as increasing capsule absorbed energy using for example 2w light (L J Suter et al, Phys Plas, **11**(5), (2004)) should also provide greater margin for employing fill tubes. For these reasons we are beginning to revisit the idea of utilizing fill pipes for ignition targets, taking advantage of developments in recent times of computational capabilities. Calculations of various fill-pipe configurations for ignition targets using the radiation hydrocode HYDRA in 2D will be presented and discussed.

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Growth of low-amplitude surface perturbations and laser imprint in directly irradiated targets*

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Hydrodynamic instabilities in ICF targets are caused by the Rayleigh-Taylor (RT) growth of perturbations that are in turn seeded by the Richtmyer-Meshkov (RM) growth of initial perturbations and those driven by imperfections of the laser deposition on the outside of the target. These initial and driven perturbations can be extremely small (or order a nanometer or less at individual wavelengths). At these levels, perturbations can be difficult for typical hydrocodes to track, and distinguishing physical growth from numerical noise can be a problem. From the linear theory of the ablative RM instability[1], we expect these processes (surface perturbation growth and laser imprint) to produce linear and predictable behavior. Previously, one of us[2] identified areas in a hydrocode where linearity can be violated and showed that a simplified code based on alternative formulations for hydrodynamics, laser deposition, and electron thermal conduction can preserve strict linearity and differentiability while maintaining signal-to-noise ratios of order 10^5. We are applying these ideas to the FAST radiation-hydrodynamics code, and will report on our progress in this area.

[1] V. N. Goncharov, Phys. Rev. Lett. 82, 2091 (1999); A.L. Velikovich, et al., Phys. Plasmas 7, 1662 (2000).
[2] S. Zalesak, Bull. Am. Phys. Soc. 48, 60 (2003).

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Multimode weakly non linear Rayleigh-Taylor Instability

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The weakly non linear stage of the Rayleigh-Taylor instability is studied in the case of two different stabilizing mechanisms: surface tension [J. Garnier et al., Phys. Rev. E 68, 036401 (2003)] and ablation. If introducing surface tension in the fluid equations is straightforward and leads to analytical growth rates in the linear stage, it is not the case for ablation, which is studied here in the simplified framework of a Sharp Boundary Model [J. Garnier et al., Phys. Rev. Lett. 90, 195002 (2002)]. The dynamics of a multimode perturbation of the interface is analyzed by means of statistical methods, taking into account quadratic and cubic nonlinear effects. The role of the initial spectrum is discussed. A saturation criterion similar to the formula proposed by Haan [S. W. Haan, Phys. Rev. A **39**, 5812 (1989)] is obtained analytically. This criterion can be written in terms of a local rms and a particular wavelength, and depends only on the dimension of the system (2D or 3D) and on the Atwood number. This result assesses the commonly used assumption that mode coupling leads to loss of memory from initial conditions in the Rayleigh-Taylor case, even in presence of a stabilizing mechanism.

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Simulations of laser-accelerated plastic targets with gold overcoats using the FAST code*

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We present one and two-dimensional numerical simulations of the hydrodynamic compression of 30-micron plastic targets coated with thin (approximately 250Å) gold layers using the FAST code. These simulations were used to design and model experiments recently performed on the Omega laser facility in which the gilded surface of each target was irradiated by a two-step pulse --- consisting of a "foot" followed by a "main drive" --- from a high-intensity laser (a profile that is thought to mimic the generic pulse shape required for high-gain fusion implosions). Both the simulations and the experiments corroborate earlier findings† that the radiation generated by a thin metallic layer during the foot pulse can establish a long-scale-length buffering plasma, which isolates the underlying plastic from laser nonuniformity and hence mitigates the effect of imprint. This result is significant for ICF research since imprint is a well-known mechanism for seeding deleterious hydrodynamic instabilities that develop during the main drive of the pulse and spoil high-gain compression. In our presentation, particular attention will be paid to addressing the role that numerical gridding, thermodynamic equilibrium, and radiative effects play in the realistic modeling of this problem.

†S.P. Obenschain *et al.*, Phys. Plasmas **9**, 2234 (2002).

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Measurements of Laser Imprint on CH and Gold Coated CH targets on the Omega laser Facility*

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Initial experiments on the NIKE KrF laser facility[1] demonstrated that the effects of laser imprint on the hydrodynamic stability of the laser accelerated targets could be controlled by the use of thin high-Z layers on the ablation surface of the targets. This result allows for significant flexibility in the design of direct-drive ICF targets.

We now extend this work to glass laser drivers by performing similar experiments on the Omega laser facility. The Omega laser was configured to drive a planar 30μm CH target with multiple, full SSD beams. The target was pre-compressed with a single, low intensity (10^{12}w/cm^2), early beam foot (~2ns) and subsequently accelerated with 3-5 full intensity beams (~5×10^{13}w/cm^2). The residual laser non-uniformities that imprint the target in the compression phase are amplified by RT growth in the acceleration phase and are measured in the experiment by x-ray radiography.

Initial results show strong imprinting by the single-beam foot and apparent target breakup by the end of the acceleration phase. The use of a 250 Angstrom gold layer on the ablation surface appears to control the imprinting to the extent that almost no growth is observed during the acceleration phase for smooth targets. Targets with an imposed 0.1μm, λ~ 60μm perturbation begin to show some growth out of the noise floor by the end the acceleration phase. The initial results indicate that the control of imprint with high-Z layer targets is a robust effect, not sensitive to the type of laser driver.

1. S.P. Obenschain et al., Phys. Plasmas **9**, 2234 (2002).

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Laser driving and shaping pulse characteristics for hydro instability mitigation in ICF targets

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In our paper [1] work we suggested that a short Laser Shaping Pulse (LSP) or "picket" lanched onto an ICF target prior to the driving ("main") pulse, produces dynamically "on the fly" a graded density profile. This mitigates the hydro instability development at least as long as the driving pulse "feels" the graded density profile, in agreement with our earlier work [2] which demonstrated mitigation of laser imprint in targets manufactured with tailored density profiles. The short, strong LSP, in turn, might produce strong shock and areal mass oscillations originating from the target or laser imperfections [3]. Subsequent studies have demonstrated the advantages of using such a LSP to shape the target adiabat, which helps reduce not only the seed for, but also the rate of the RT growth [4, 5].

In this work we use well-resolved single-mode 2-D numerical simulations to characterize the stabilizing effect of the LSP, varying the shape of the driving pulse (standard foot vs. weaker or no foot), the time interval between the LSP and the start of the driving pulse, the duration and the energy of the LSP. We demonstrate that variation of any of these parameters strongly influences the stabilizing effect of the LSP, and discuss the optimization criteria for stabilizing the target implosion in the high-gain regime [6] without strongly affecting the target adiabat.

Work supported by the U. S. Department of Energy and performed at the Naval Research Laboratory.

[1] Metzler *et al.*, Phys. Plasmas **9**, 5050 (2002).
[2] Metzler *et al.*, Phys. Plasmas **6**, 3283 (1999).
[3] A. L. Velikovich *et al.*, Phys. Plasmas **10,** 3270 (2003).
[4] V. Goncharov *et al.*, Phys. Plasmas **10**, 1906 (2003); J. Perkins *et al.*, Bull. Am. Phys. Soc. **47**, 101 (2002).
[5] K. Anderson, R. Betti, Phys. Plasmas **10,** 4448 (2003); **11**(5) (2004).
[6] A. J. Schmitt *et al.*, Phys. Plasmas **11**(5) (2004).

Poster session preferred.

Studying the Burn Region in ICF Implosions with Proton Emission Imaging

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Pinhole cameras are being used to image the burn regions in implosions of capsules with both thin (~2-μm-glass) and thick (~20-μm-CH) shells on OMEGA. Capsules with D_2 and D^3He fill have been studied with proton core imaging spectroscopy (PCIS). The differences in burn-region size will be explored for different shell types and laser characteristics, and the burn profile shapes will be compared for primary DD, primary D^3He, and secondary D^3He reactions. In addition, multiple pinhole cameras are being used to image the burn region of asymmetrically driven implosions from three orthogonal directions. Images of asymmetric burn will be interpreted and compared to x-ray images.

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Prefer poster presentation.

Spectra of scattered and emitted light in modeling of High intensity laser plasma interactions.*

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We examine synthetic streak spectra of light scattered or emitted in laser target simulations done with our massively-parallel PIC code Z3. The first example features stimulated scatter in an intense speckle at high electron temperature, corresponding to small targets and ~ 1 ns pulses. These multiple-dimensional simulations show scatter cascades as in previous work[1]. Brillouin rescatter of Raman forward scatter, at frequency distinct from Raman backscatter, occurs in bursts and with an angular spread consistent with the scattering volume. In the second example, we postprocess simulations of shortpulse ultra-high intensity LPI[2], both for scatter from the front of the target and for harmonic emission from back surfaces, for comparison to experiment.

*This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

1. "Nonlinear Evolution of Stimulated Scatter in High-Temperature Plasmas", A. B. Langdon and D. E. Hinkel, Phys. Rev. Lett. **89**, 015003 (2002).
2. C. H. Still, B. F. Lasinski, and A. B. Langdon, "Modeling of Short Pulse High Intensity Laser-Plasma Interactions in 2 & 3D PIC Simulations," this conference.

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Laser Plasma Interactions in NIF ICF target designs*

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ICF target designs have evolved incrementally from the original point design. Intensities are lower, the hohlraum walls may be coated with low-Z material, and 2• illumination is under consideration. These changes indicate that a reevaluation of the anticipated LPI problems is warranted. Using the NEWLIP post-processor, convective gains for forward and backward SRS and backward SBS are evaluated, together with the criterion for filamentation/beam spray for both the inner and outer beams. The scaling of LPI gains with hohlraum size (and required laser energy) are found to be quite weak, facilitating a "pop-up" strategy, where most of the ignition campaign is performed below maximum laser energy, with scaled targets. We find that the composition of the hohlraum gas-fill is not very significant. (Which is good, given that hydrogen-containing hohlraum gas fills, with frozen DT capsules, now appear quite problematical to field.) In addition, we estimate the effects of crossed-beam energy transfer, extending our work to consideration of polarization smoothing and beryllium as well as CH lining on the laser entrance hole.

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A NIF 3-D jet experiment*

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Some ICF ignition capsule designs for the National Ignition Facility (NIF) require localized features such as fill tubes, holes, and waist joints, which break the ideal spherical symmetry of the capsule. Shock passage through a shell feature can generate a jet of shell material into the DT fuel. An experiment using the first four beams of NIF was performed to examine the dynamics of such a feature. The hydrodynamic response of a pusher void to a high Mach number shock was examined with a mini-shock tube. The shock was generated by direct illumination of a CH ablator by a 3 kJ 1.5 ns NIF laser pulse. The pressure of the ablator drove a blast wave through a 250 μm thick planar aluminum pusher into density 0.1 g/cm^3 carbon foam enclosed in a CH tube. The shock pressure in the Al was 20-60 Mb, the lower value applying at breakout into the foam, yielding a shock Mach number in the Al of about 8. We compared the behavior of a 2-D axisymmetric feature to a 3-D feature. The 2-D feature was a cylindrical void of 160 μm diameter and 150 μm depth penetrating into the Al from the interface with the foam. Shock passage over the void launched a jet of Al into the foam, which was diagnosed with point x-ray backlighting. The 3-D feature was a hole tilted by 45°, also 150 μm deep relative to the surface normal. Data are in reasonable agreement with simulations using the ALE code, Hydra. NIF shots in January-February 2004 had a spot profile which was more centrally-peaked than desired, resulting in greater sensitivity to beam pointing. One shot showed a tilted jet resulting from an axisymmetric void, but could be matched by assuming an off-center spot. The shape of the simulated jet also shows sensitivity to the foam equation of state. More shots will be performed in April-May, for which we anticipate ~6 kJ of laser energy and a flatter spot profile. The higher energy will allow us to examine more-evolved structure as the backlighter delay is constrained to ≤ 21 ns.

* This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

34th Annual Anomalous Absorption Conference
Gleneden Beach, Oregon
May 2-7, 2004

Analytic Expressions For Optimal Hohlraum Wall Density and Minimal Wall Loss *

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We apply recent analytic solutions [1] to the radiation diffusion equation to problems of interest for ICF hohlraums. The solutions provide quantitative predictions for absorbed energy, which are of use for generating a desired radiation temperature vs. time within the hohlraum. Comparison of supersonic and subsonic solutions (heat front velocity faster or slower, respectively, than the speed of sound in the x-ray heated material) suggests that there may be some advantage in using high Z metallic foams as hohlraum wall material to reduce hydrodynamic losses, and hence, net absorbed energy by the walls. Analytic and numerical calculations suggest that the loss per unit area might be reduced ~ 20% through use of foam hohlraum walls and that this reduction factor is "universal" – independent of drive and pulse-length. We derive an explicit expression for the optimal density (for any given drive temperature and pulse-length) that will achieve this reduction factor. Additional approaches to reducing wall loss, (e.g. cocktail mixtures of hohlraum wall material to raise opacity), can be used in conjunction with this approach to even further reduce the losses and hence ultimately substantially reduce the cost of a reactor driver.

1. J.H. Hammer and M. D. Rosen, "A consistent approach to solving the radiation diffusion equation," *Physics of Plasmas* **10**, 1829 (2003).

* This work performed under the auspices of the U.S Department of Energy by University of California, Lawrence Livermore National Laboratory under contracts No. W-7405-Eng-48.

34th Annual Anomalous Absorption Conference
Gleneden Beach, Oregon
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Calculations for NIF first quad gas-filled hohlraum experiments testing beryllium microstructure growth and laser plasma interaction physics*

S. R. Goldman, J. C. Fernandez, N. M. Hoffman, and J. M. Kindel

Los Alamos National Laboratory

A.B. Langdon

Lawrence Livermore National Laboratory

The first quad of the NIF provides four nearly collinear f/20 laser beams, which can be treated as a single f/8 beam of maximum energy 16 kJ. We are providing designs for experiments on halfraums in which the composite beam is focused in the plane of the (single) halfraum laser entry hole (LEH) with its symmetry axis collinear with the halfraum symmetry axis. For most of the calculations, the halfraum diameter is 1.6mm, the LEH is 1.2mm, and axial length is 3.0mm. The incident laser power consists of an early foot followed by a final peak. Peak radiation temperatures for this relatively narrow hohlraum are greater than for wider hohlraums of the same length. Plasma conditions within the halfraum are calculated with Lasnex using azimuthally symmetric, (r,z) geometry, taking into account a polyimide membrane which contains the fill gas (CH_2) within the halfraum. Estimates for microstructure growth due to the volume crystalline structure within a beryllium slab mounted in the halfraum sidewall are obtained by a post-processor, which applies plasma conditions within the halfraum to an ablatively accelerated, one-dimensional beryllium slab. We compare the results of a series of calculations of increasing precision in definition of the laser ray drive and hohlraum zoning. There are significant differences in plasma conditions for the foot when pressures in the hohlraum sidewall are of order 1Mbar; accurate specification of these conditions is necessary for establishing the connection between the instability growth due to volume crystalline structure within the beryllium slab and ordinary ablative Rayleigh-Taylor growth due to surface structuring. Plasma conditions in the peak are also affected by improved resolution. We are currently attempting to model the consequences of possible beam filamentation during the pulse.

*Work supported by USDOE

34th Annual Anomalous Absorption Conference
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Laser Wakefield Acceleration of auto-self-trapped electrons to ~1GeV in a plasma channel*

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The auto-self-trapping and laser wakefield acceleration of electrons is studied in three-dimensions using the particle-in-cell (PIC) code OSIRIS.framework. The simulations model a 50fs, 16.5 TW, .8μ m laser propagating through a leaky plasma channel with a minimum density of 3 10^{18} cm^{-3}. The initial wake is not large enough to trap background electrons. However, the self-consistent evolution of the laser due to photon acceleration and deceleration, group velocity dispersion, and transverse self-focusing results in larger wakes and a transverse dephasing of the electrons orbits leading to self-trapping. This first group of particles beam loads and eventually stretches the wake, leading to the trapping of a second bunch of electrons. The first bunch eventually reaches 480 MeV (with a beam distribution), while the second bunch approaches 840MeV(with a continuous distribution). We will discuss the evolution of the laser, the auto-self-trapping, the acceleration mechanism, the modification to the beam as it exits the plasma and the difference between 2D and 3D simulations. The simulations followed particles on 3600 x 256 x 256 grids for a distance of .94 centimeters.

* Work supported by DOE and NSF. The simulations were performed on the IBM SP @ NERSC under the SciDAC allocation.

Prefer Poster

Energetic Electron Characteristics in Fast Ignition

C. Ren[a], M. Tzoufras[a], F. S. Tsung[a], W. B. Mori[a], S. Amorini[b], R. A. Fonseca[b], L. O. Silva[b], J. C. Adam[c], and A. Heron[c]
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[c]Ecole Polytechnique, France

In the fast ignition concept of inertial fusion energy, a cold highly dense core of highly compressed fuel is to be ignited by energetic electrons produced by an intense laser beam at the laser-plasma critical surface. The characteristics of the energetic electron flux, such as the energy spectrum and angular spread, is essential information needed to determine how energy ultimately reaches the core. Fully-kinetic particle-in-cell (PIC) simulations are the only tool available for obtaining this information. Based on a series of large two-dimensional PIC simulations (first presented in the last year's conference in Lake Placid) using the OSIRIS framework, we have characterized the incoming electron spectrum under different conditions such as target geometry, laser polarization, and simulation box size. In particular, we will describe how the spectrum and angular spread change when the laser intensity is raised from 10^{20} W/cm^2 to 10^{21} W/cm^2. These results will also be indispensable input for other non-PIC codes to study the energy transport in the dense core region.

Work supported by DOE Contracts Nos. DE-FG03-NA0065 and DE-FG02-03ER54721.

Creating uniform plasmas with short-pulse lasers by field and collisional ionization

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15 March 2004

Laser plasma interactions depend on the uniformity of the plasma density, temperature, or flow velocity. Gas jets and gas balloons have been used to provide initially uniform gas profiles. However, the process of plasma production usually involves ionization and heating with non-uniform laser beams over hundreds to thousands of picoseconds. During this time the plasma has sufficient time to develop nonuniformities that can affect the laser plasma interaction, *e.g.* stimulated Raman scattering. Here we consider producing a low electron density hydrogen plasma "channel" with a short pulse whose peak intensity is a few times the hydrogen ionization potential. The optimum beam focus and pulse duration are about the plasma length. For such short times, the plasma ions cannot respond fast enough to alter the initial uniformity. Both field ionization and collisional ionization play important roles. Simulations of plasma channels 3 mm long and 80 microns wide in 1% critical plasma will be shown. [1]

[1] Work performed under the auspices of the U.S. Department of Energy by University of California Lawrence Livermore National Laboratory under Contract No.W-7405-ENG-48 and U.S. D.o.E. Contract No. DE-AC02-76-CHO-3073.

Short pulse lasers for the development of broadband x-ray sources*

Ronnie Shepherd[1], Hui Chen[1], Hyun-Kyung Chung[1], Robert Heeter[1], Denise Hinkel[1], Nobuhiko Izumi[1],Jeff Koch[1], Jaroslav Kuba[1], Mark May[1], Andy Mackinnon[1], Steve Moon[1], Hye-Sook Park[1], Prav Patel[1], Richard Snavely[2], Marilyn Schneider[1], Max Tabak[1], Scott Wilks[1], Mike Key[1], Paul Springer[1], Peter Beiersdorfer[1], Kramer Akli[2], Daniel Hey[2], Jim King[2], Bingbing Zhang[2], Rick Freeman[3], Christian Stoeckl[4], Wolfgang Theobald[4], Marco Borghesi[5], Satya Kar[5], Lorenzo Romangnani[5], Abbas Nikroo[6], Rich Stephens[6], Pete Brummitt[7], Rob Clarke[7], Colin Danson[7], Steve Hawkes[7], Rob Heathecote[7], Christina-Henandez-Gomez[7], David Neely[7], Darren Neville[7], Martin Tolley[7], Richard Eagleton[8].

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We have performed a set of bench-mark experiments on holhraums at the Rutherford Appleton Laboratory. Copper hohlraums were heated with a 400 J, 1 ps, pulse focused to a 5 μm spot size. The hohlraum diameters varied from 250 μm to 800 μm with a 10 μm wall thickness. Several measurements were performed to estimate the plasma scale-length, heating mechanism, and thermal temperature. These data will be discussed along with the analysis.

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Laser plasma coupling with moderate Z, long scalelength underdense plasmas*

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R. M. Stevenson and K. Oades
Atomic Weapons Establishment, Aldermaston, UK

Recent experiments[1,2] have focussed new attention on the coupling of laser light with moderate Z, long scalelength underdense plasmas. We discuss some intriguing features of these experiments, including a significant reduction of stimulated Raman and Brillouin scattering in higher Z plasmas, such as Krypton and Xenon. Threshold conditions for various instabilities are discussed, and potential consequences of thermal filamentation and self-focussing are explored. The presence of significant temperature modulations in the plasma can lead to a number of interesting effects not usually taken into account, such as ion wave refraction out of hot spots. We also consider the extrapolation of these results to the higher temperature regimes more relevant to ignition-scale hohlraums.

1. R. M. Stevenson, *et. al*, Phys. Plasmas (in press)
2. J. Moody (to be published)

**Work performed under the auspices of the U.S. DOE by the Lawrence Livermore National Laboratory under Contract W-7405-ENG-48.

PARTICLE-IN-CELL SIMULATIONS OF THE $2\omega_p$ INSTABILITY

F. S. Tsung, W. B. Mori – UCLA*, B. B. Afeyan -- Polymath Research Inc.**

A particle-in-cell code (OSIRIS) is used to investigate the linear and nonlinear evolution of the two-plasmon decay instability in a nonuniform density profile. Our studies show good agreement between the simulation and linear inhomogeneous plasma theory by Afeyan et al. (Phys. Plas. **4**, 3827, 1997.) By varying the lateral width of the laser drive, as would occur in a laser hot spot, for example, the two-plasmon decay instability can be controlled and even suppressed and our simulations have verified this. As the simulation progress, the plasmons will accelerate electrons, some of which are relativistic. The temperature of the fast electrons appears to follows Coffey's wave breaking prediction (T. Coffey, Phys. Fl. **14**, 1402, 1972.) We wish to understand the fast electrons' role in the saturation and recurrence of the two-plasmon instability. Ion effects will be included. On a longer timescale, the nonlinear interaction of plasmons can move ions and subsequently change the saturation level and the temperature of the hot electrons. This effect can be shown explicitly by evaluating the bicoherence of the electrostatic potential. We will present the implementation and the results of this diagnostic in the meeting.

* Work supported by DOE and NSF.
** Work supported by NRL.

Fast Electron Generation from the Two-Plasmon Decay Instability in Long-Scale-Length Plasmas*

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Energetic electrons from instabilities in the underdense plasma are a major preheat concern. The two-plasmon decay (TPD) instability at the quarter critical density can generate highly energetic electrons via nonlinear plasma wave evolution. The spectrum of energetic electrons depends on several factors, e.g., profile steepening, ion dynamics, and plasma density gradient scale lengths. We have developed a 2.5D particle-in-cell (PIC) code which we use to study the nonlinear evolution of the TPD instability and its role in energetic electron generation. We will present scaling relationships between the energetic electron spectrum and laser power density and other quantities. We will compare the PIC results with analytical models for the nonlinear evolution of the TPD and associated suprathermal electron tail formation.

*Work supported by U.S. Department of Energy

Poster session

Vlasov-Maxwell SRS Simulation for a Parabolic Density Profile with Injected Seed Light

Marc Albrecht-Marc (a), Thierry Réveillé (a), Alain Ghizzo (a), Pierre Bertrand (a), B. Afeyan (b) and T.W. Johnston (c)

(a) Université Henri Poincaré, Nancy, France,
(b) Polymath Research Inc., Pleasanton, CA
(c) INRS, Varennes, Quebec, Canada

The interim results will be reported of Vlasov-Maxwell 1.5-D simulations with injection of low levels of electromagnetic seed light into a parabolic density profile. Anomalies and apparent anomalies of these results (with respect to expectations from fluid theory for coupled modes) will be discussed. These include the growth and saturation of the plasma oscillations and the SRS backscatter and the link with kinetic effects which are absent in fluid theories. The distinctive kinetic phase space features found in these Vlasov simulations seem not to be the dominant features as cited from PIC results reported in the literature (e.g., [1]) so that their relationship between the two simulations and the results remains to be clarified.

[1] H.X. Vu et al. Phys. Plasmas, **9**, 1745 (2002)

Tuesday, May 4, 2004

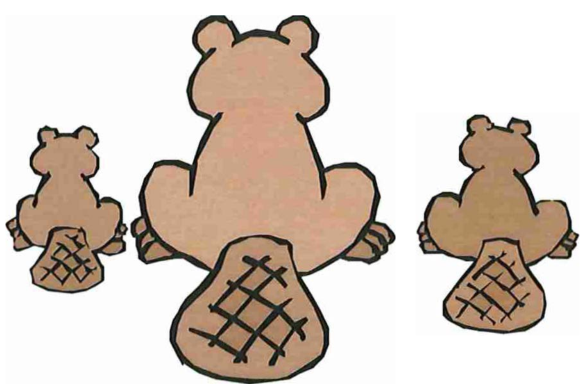
Daily Program

8:00 AM - 8:45 AM	**Continental Breakfast**
8:45 AM	**Conference Begins**
8:45 AM -10:25 AM	**Oral Session 2**
10:25 AM -10:55 AM	**Break**
10:25 AM -12:55 PM	**Oral Session 2 Cont**
7:30 PM -8:30 PM	**Invited Session 2**

Dr. R. Lee

Plasma- related research on future FXELs

8:30 PM -11:00 PM	**Poster Session 2**



Oral Session 2

~~J. M. Kindel~~, Chair

Laser-Ablation Treatment of Short-Pulse Laser Targets: Towards an Experimental Program on Energetic-Ion Interactions with Dense Plasmas*

Juan C. Fernández, B. Manuel Hegelich, James A. Cobble, Samuel A. Letzring, Randall P. Johnson, D. Cort Gautier, Tsutomu Shimada, Jörg Schreiber[1)]
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This new project relies on the capabilities collocated at Los Alamos in the Trident laser facility of long-pulse laser drive, for laser-plasma formation, and high-intensity short-pulse laser drive, for relativistic laser-matter interactions. Specifically, we are working to understand quantitatively the physics that underlie the generation of laser-driven MeV/nucleon ion beams, in order to extend these capabilities over a range of ion species, to optimize beam generation, and to control those beams. Furthermore, we intend to study the interaction of these novel laser-driven ion beams with dense plasmas, which are relevant to important topics such as the fast-ignition method of inertial confinement fusion (ICF), nuclear-weapons physics, and planetary physics.

As demonstrated on several facilities worldwide (*e.g.*, Nova PW, LULI, Vulcan, Trident), the interaction of high-energy sub-ps lasers with foil targets can result in efficient acceleration of protons to multi MeV energies. On the Nova PW, a conversion efficiency of laser to ion energy of up to ~ 10% was observed with gold-foil targets [1]. The protons come from impurities adsorbed on untreated metal foils. Metal-foil targets yield proton beams with an ultra-low transverse emittance, which is a crucial advantage of using lasers for ion-beam generation. The next step in harnessing short-pulse lasers to produce beams of heavier ions is the use of *in situ* Joule heating to evaporate impurities that contain hydrogen [2]. With such targets, the proton content in the beam (and the energy thus consumed) can be made negligible. Unfortunately, this technique does not remove other impurities with binding energies in the eV range, such as metal oxides.

Target-surface impurities obstruct our aim of accelerating primarily and efficiently the metallic ions in the foil substrate. In order to quantify the problem, measurements of surface impurities on typical metallic-foil laser targets have been made. To eliminate these impurities, we have resorted to laser-ablation using a long-pulse laser intensity of $\sim 10^{10}$ W/cm^2. Our progress on this promising effort is presented in this paper.

[1] R. Snavely, et al., *Phys. Rev. Lett.*, **4** (2000) 2945
[2] B. M. Hegelich, et al., *Phys. Rev. Lett.*, **89** (2002) 085002

*Supported by the LANL Laboratory Directed Research & Development program.

ACCELERATION PHYSICS OF LASER-DRIVEN MEV-ION BEAMS

B. Manuel Hegelich[1], J. Schreiber [2,3], P. Audebert[4], E. Brambrink[6], J. Cobble[1], J. C. Cooley[1], T. Cowan[5], R. D. Field[1], J. Fuchs[4,5], S. Gaillard[5], S. Letzring[1], P. Papin[1], U. Schramm[3], E. Veuillot[4], K. Witte, D. Habs[3], J. C. Fernandez[1]

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While the acceleration of the high-energy protons by ultrahigh intensity lasers is adequately described by the Target Normal Sheath Acceleration (TNSA) model by Hatchett et al. [1], multiple ion species and charge states have never been part of this model. Neither the origin of individual charge states, temporal as well as spatial, nor their spectrum or beam properties are so far reproduced by any simulation. Our recent experiments suggest similar beam profile and emittance qualities for the heavier species as observed for protons. But the heavier ion beams have a multiplicity of charge states [2,3], each possessing different characteristics. Moreover, our results suggest the presence of TV/m acceleration fields at depths of up to 50nm below the target rear surface in special target geometries. While providing a partial answer for the spatial origin of lower charge states, these results also pose interesting new questions concerning the influence of material characteristics such as conductivity, and the influence of material interfaces on the electron transport and thus on the acceleration physics. Together with former source size measurements at the rear surface, our results also set a lower bound on the source volume, which now stands at 10^{15} ions. Since only about 10^{13} ions are accelerated to MeV energies, this raises the question of selection rules within the acceleration process, i.e. which ions gain high energies, when and why. Answering these questions might lead to a far better control of the acceleration process.

[1] S. Hatchett *et al.,* Phys. Plasmas, **7,** 2076 (2002).
[2] M. Hegelich *et al.*, Phys. Rev. Lett. **89**, 085002 (2002).
[3]M. Hegelich *et al.*, APSDPP, Albuquerque, (2003)

Acceleration of fast ions with multiple charge states in short pulse laser experiments*

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Recent Trident short pulse experiments conducted by Hegelich, Cobble, and Fernandez have demonstrated the production of fast low- to moderate-Z ions with multiple charge states at the backs of the thin targets. To understand the ionization and acceleration mechanisms, the authors have developed a hybrid code that can be interfaced with a fully relativistic particle-in-cell (PIC) simulation. The hybrid model solves a nonlinear Poisson equation to obtain the electrostatic potential and electron density within the ion layer with a match at the boundary to an analytic solution to the relativistic Vlasov/Maxwell equations for the virtual cathode. Simple ionization and recombination kinetics are included to capture atomic kinetics relevant to the Trident experiments. Two key advantages of the hybrid approach over traditional PIC are that one only needs to resolve the length and time scales appropriate for the ions (i.e., smaller simulation domain and longer time steps) rather than those of the hot electrons; and, the noise levels associated with finite electron particle numbers are lower.

The hybrid model predicts that in Trident-relevant experiments the ions with the largest charge-to-mass ratio will receive the most energy; how much energy resides in these states relative to the other ionization states will be discussed. Atomic kinetics, including field ionization, charge exchange, and collisional ionization will also be considered. Previous attempts at understanding theoretically laser-ion acceleration experiments [Begay and Forslund, Phys. Fluids 25, 1675 (1982)] which considered the acceleration of various ionization states of carbon ions indicated that the ions were being accelerated at one charge state but collected by the Thomson parabola in another state. The physics underlying this interpretation has remained an unresolved issue, though one which should be amenable to techniques as described here.

*This work was performed under the auspices of the U.S. Department of Energy (DOE) by the University of California Los Alamos National Laboratory under contract W-7405-ENG-36; the work was supported by the LANL Laboratory Directed Research and Development (LDRD) program.

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Charge Separation Effects in Solid Targets and Ion Acceleration with Two-Temperature Electron Distributions

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P. N. Lebedev Physics Institute, Russian Academy of Sciences, Moscow, Russia
[5] Dipartimento di Fisica "G. Occhialini" and INFM, Universita degli Studi di Milano-Bicocca, Milan, Italy

The electrostatic field at the solid-vacuum interface generated by two electron populations with different thermal energies is analytically derived from the Poisson equation and studied in terms of plasma parameters. The effect of the pressure of each of the two populations on the amplitude of the electric field and on its spatial extension is described.

The cold electron temperature is evaluated from a model, which accounts for the Ohmic heating of the background electron population by laser-generated fast electrons. The consequences on ion detachment, ionization and acceleration processes in laser-solid experiments are discussed.

The acceleration of light and heavy ions from the rear side of a thin solid target is studied numerically by using a hybrid Boltzmann-Vlasov-Poisson model. Spatial profiles, energy distributions, and maximum energies of accelerated ions are analyzed in function of the plasma and hot electron parameters. A special attention is paid to characterization of protons accelerated from a thin hydrogenated layer at the target surface. The evolution of proton spectrum is studied for the cases of isothermal and cooling hot electron distributions.

The obtained dependencies of the ion energy on the pulse duration and the target characteristics allow the definition of optimal conditions for the ion acceleration with lasers.

3D Simulations and Modeling of the Ionization Scattering Instability*

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The propagation of laser pulses with high peak power and short pulse duration in tenuous gases and plasmas is of interest in many areas of applied physics such as Laser Wakefield Acceleration, and Atmospheric Propagation. However, modeling and simulating the propagation of these is difficult due to the complex nature of the matter response as the laser pulse power increases. For instance, in neutral gas a laser pulse can undergo self-focusing due to the non-linear response of the atoms to the pulse[1]. We have developed a new three-dimensional simulation capability based on the extended paraxial approximation to the laser pulse evolution[1] and coupled to various material dielectric responses. For instance, when this laser propagation code is coupled to a quasi-static kinetic plasma response we get a laser-based quickPIC[2]. For the current work, we couple the laser propagation code to a model that includes the non-linear electronic response to the laser pulse as well as ionization and a fluid plasma response to the ponderomotive potential from the laser.

We will present the first three-dimensional simulations of an instability that occurs in a tenuous gas undergoing ionization. This instability has been termed the ionization scattering instability[3] and is due to the coupling of the primary pump laser pulse and small amplitude scattered waves in the ionization rate. Specifically, both tunneling ionization and multi-photon ionization depend strongly on the local magnitude of the electric field. Thus, the local ionization rate can be affected by small amplitude scattered waves beating with the pump laser pulse. This modified electron density can then lead to enhancement of the scattered wave due to the material dielectric response. This instability has been characterized in both one and two-dimension[3]. We have performed simulations to examine the three-dimensional nature of this instability and compare our current results with the two-dimensional case. We also compare the relative importance of this instability to the self-focusing instability alluded to above and discuss under what conditions these two instabilities are likely to dominate.

*Work supported by NSF and DOE

1. Wu, J.Z. and T.M. Antonsen, *Laser pulse splitting and trapping in tenuous gases*. Physics of Plasmas, 2003. **10**(6): p. 2254-2266.
2. Cooley, J.H., et al., *Further Developments for a Particle-in-Cell Code for Efficently Modeling Wakefield Acceleration Schemes*, AIP Conference Procedings, vol **647**, p. 232-239, editors Clayton and Muggli
3. Bian, Z.G. and T.M. Antonsen, *Ionization instabilities of an electromagnetic wave propagating in a tenuous gas*. Physics of Plasmas, 2001. **8**(7): p. 3183-3194

Transport of Relativistic Electrons for Modeling Fast Ignition in the 2-D Hydrocode *DRACO*

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To simulate fast ignition in direct-drive inertial confinement fusion, a simplified relativistic-electron transport model has been introduced in the multidimensional hydrodynamic code *DRACO*. In the model, the electrons are introduced at the pole of a 2-D simulation at an appropriate thermal electron density and are transported in a straight line toward the target core. The energy deposited by the electrons in the background plasma is calculated using the slowing-down formulas by Li and Petrasso.[1] The fast-electron model is applied to an OMEGA cryogenic target designed to reach a 1-D fuel ρR of 500 mg/cm^2 in order to assess the effect of a fast-ignitor beam from the proposed high-intensity, short-pulse OMEGA EP (extended performance) laser. Sensitivity to energy, timing, and irradiance of the Gaussian electron beam will be presented. Neutron yields in excess of 10^{15} are expected over a timing range of about 80 ps.

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1. Submitted for publication

Oral presentation preferred.

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2-D Implicit PIC/Hybrid Modeling of Ultra-Intense Laser-Matter Interactions*

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The Fast Ignitor approach[1] to Laser Fusion will require target absorption of ~10^{2} W/cm^2 picosecond 1 μm laser pulses into DT fuel compressed 10^3-fold to 5×10^{25} electron/cm^3 densities. The energy will be carried throughout the target by relativistic hot electrons, perhaps with fast ions as an intermediary. Ultimately, the energy must raise the background DT to ignition temperatures. Modeling of this transport phenomenology is beyond traditional hydro codes, due to the need for a multi-dimension self-consistent hot electron component. It challenges traditional explicit PIC codes, due to the high densities encountered, requiring more than 10^8 cells in 2-D to resolve the miniscule Debye length. Our 2-D ANTHEM model surmounts these difficulties, via an implicit solver for the *E&B*-fields, and a relativistic fluid treatment for the background electrons. For the hot particle electrons we use a simple, centered predictor-corrector scheme, subsequently accumulating a number of moments including relativistic momentum and pressure. For the possibly relativistic background fluid electrons we advance mean momenta in a Van Leer, second order prescription. Relativistic "super temperatures," as a measure of the mean square random momenta, are increased by *PdV* heating, and used with the momenta to compute fluid Lorentz γ-factors. The various component moments then give *E&B*-fields through the Implicit Moment Method[2]. Velocity weighting of the emitted relativistic electrons adds to the dynamic density range. The hot electrons undergo drag and scatter against the background. Scatter of the returning cold background electrons sets up a resistive *E*-field that can deflect incident hots at early cold background plasma times. Light is transported along the mesh and dumped isotropically into the electrons at critical. Gradients in the intensity yield substantial ponderomotive forces that work to launch an axial, laser-aligned jet of hot electrons into the target. We show that multiple reflections tend to fill a finite target, say a 40 x 20 μm foil, nearly uniformly with hot electrons after 1 ps, launching fast ions from all surfaces at the hot electron density. At 10^{20} W/cm^2 the deposition surface is irregular, showing mild instability, not clearly Weibel related, strong $E \times B$ surface drift[1], and target dependent internal transport.

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*Work supported by the USDOE

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Hybrid Particle-in-Cell Simulations of MeV Electron Transport in Fast-Ignition Targets

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One of the central issues surrounding the fast-ignitor (FI) approach to inertial confinement fusion is our understanding of the ability of an intense electron beam, carrying $I_{beam} \sim 10^8$ A of current, to propagate through many tens of microns of compressed fuel. Previous three-dimensional numerical studies of fast-electron transport in dense plasmas using a hybrid-implicit particle-in-cell (PIC) approach[1] are extended to investigate the sensitivity of the current filamentation and magnetic-field generation to the hot-electron source distribution. Both power law[2] and warm-beam energy distributions are investigated.

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Prefer oral presentation

Space Charge Effects in the Filament Instability of Current Beams in a Plasma

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The fast ignition concept for inertial confinement fusion calls for propagation of an intense beam of energetic electrons produced by a PW-class laser into an overdense plasma. The beam current is on the order of 300 MA and as it propagates forward it induces a return current in the background plasma to make the net current zero. In particle-in-cell (PIC) simulations, a filament structure is observed in the particle density (both electron and ion), current density, and magnetic field profiles. This filament structure is attributed to a transverse electromagnetic or Weibel instability of the beam and return currents. The standard theory usually assumes a purely transverse mode ($k \bullet E = 0$) and only considers the electron's contribution.

However, for a single current beam, any current filamentation is always accompanied by charge filamentation and therefore an electrostatic field would develop along k. Only when this space charge is neutralized by an out-of-phase filament structure from the return electrons and/or ions can the mode be purely transverse. We present a non-relativistic theory taking into account the coupling of the transverse and the longitudinal modes to illustrate this physics. According to this theory, due to the disparity of the transverse temperature between the beam and return electrons, the beam and return current cannot pinch to the same degree and the space charge cannot be completely cancelled between them. This will raise the instability threshold. However, at a lower growth rate (on the order of the ion plasma frequency), a cold ion species can react to completely neutralize the residual space charge and the mode can be purely transverse (i.e., rid of any space charge contribution) with a lower instability threshold. (For the relativistic theory and its application to the fast ignition simulation results see the presentation by M. Tzoufras *et al.* at this conference.)

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34th Annual Anomalous Absorption Conference
Gleneden Beach, Oregon
May 2-7, 2004

Harmonic emission from the rear side of thin overdense foils irradiated with intense ultrashort laser pulses

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The harmonic emission from thin solid carbon and aluminum foils irradiated by 150 fs long frequency doubled Ti-sapphire laser pulses at λ=395 nm and peak intensities of a few 10^{18} W/cm^2 has been studied. The laser pulse is incident p-polarized under an angle of 45°. The harmonic emission from the rear side of the foils has been studied in the direction of the incident light. The foil thickness was in the range 0.2 to 1 λ. Due to the low prepulse level of the laser pulse the foils remain overdense during the interaction with the main pulse. Since the overdense plasma is opaque for frequencies below its plasma frequency ω_p, one would expect that only harmonics above ω_p are observable at the rear side, because only these harmonics are transmitted from the front to the rear. Nevertheless, we observe strong rear side emission of the harmonics below ω_p including the fundamental, while at ω_p a strong cutoff occurs. In addition to high order harmonic spectra, we present the conversion efficiency, the angular distribution, the polarization properties and the spectral shape of the fundamental emitted from the rear side.

The experimental observations are well reproduced by one-dimensional PIC simulations. They reveal that strong reemission occurs when the conditions for resonance absorption are met, i.e. when the density gradient is optimal for resonance absorption. The coupling from the laser irradiated front side to the rear side occurs via the energetic electrons generated in the process of resonance absorption. These electrons propagate through the foil and excite plasma oscillations in the whole foil at multiples of ω_p.

This work was supported in part by the European Communities in the framework of the Euratom-IPP association and the Deutsche Forschungsgemeinschaft (DFG grants TE190/4-1 and TS82/1-1).

Evidence of Spatially Coherent Synchrotron Radiation from Laser-Plasma Interactions

master's thesis

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When driven by a circularly- or linearly- polarized laser with an intensity above 10^{19} W/cm^2, electrons in a plasma experience sufficient accelerations to emit synchrotron radiation into the UV and beyond. Such radiation would typically be unobservable unless many electrons radiate coherently. Although the electrons are all driven by the same laser, one might expect nonlinearities and density variations in a typical laser-created plasma to destroy this coherence.

We present recent experiments on the 100fs USP laser at Lawrence Livermore National Laboratory which strongly indicate that, despite these expectations, electron orbits can nevertheless maintain spatial coherency over a significant distance (>20μm along the laser axis). The primary diagnostic is easily-observable radiation in the 295-305nm range, far from any harmonics of the 800nm laser. This radiation is observed to be emitted into a very narrow plane (~2 mrad in one dimension), perpendicular to the laser axis. Because this angle is much smaller than any other angle defined in the experiment, we interpret this radiation as the far-field of numerous coherent oscillators. Experimental results are presented and discussed for both linear- and circular- polarized lasers incident upon solid Aluminum and Tungsten targets. The inferred spatial coherency also implies an unpulsed signal, flatly contradicting the proposed "lasetron" scheme to create zeptosecond bursts of xrays using circularly polarized lasers [1].

[1] A.E. Kaplan and P.L. Shkolnikov, Phys. Rev. Lett. **88**, 74801 (2002).

Oral Session requested

Invited Session 2

R. L. Kauffman, Chair

“ Plasma-related research on future FXELS ”

R. Lee

Poster Session 2

Target Fabrication and Characterization for High Energy Density Physics Experiments

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General Atomics' Inertial Fusion Technology target fabrication group and its partner, Schafer Corporation's Schafer Laboratories, produce targets and components for High Energy Density Physics experiments in collaboration with the national labs. These components and targets involve precision machined and foam components as well as capsules with a variety of compositions and dimensions. Examples include planar targets with precision machined steps or patterns for EOS or ICE experiments, machined cylindrical components with marker bands, shaped foam components, or full target assemblies for complex double shell capsules, spherical targets with high Z surfaces or buried layers. In addition, a full suite of metrology techniques are employed for precise characterization of these targets. Examples include a method of characterizing the full surface finish of shells and high precision radiography to measure optical depth variations to $\sim 10^{-4}$ .Here we present a general overview of our fabrication and characterization capabilities and present some specific targets produced for HEDP purposes in recent years.

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Reduction of laser beam spray at 0.527 μm in an ignition scale length plasma with temporal beam smoothing*

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We have measured the effect of temporal laser smoothing by spectral dispersion (SSD) on beam spray, transmission and deflection of a 2ω (527 nm) high intensity (10^{15} W/cm^2) interaction beam through an underdense large-scale length plasma. The experiments were performed at the Omega laser facility using the newly commissioned transmitted beam diagnostics (TBD). The large scale length plasma is created by heating a mm-sized CH-gasbag target with 39 defocused heater beams at 3ω, delivering a total energy of 10.5 kJ in a 1 ns square pulse. The TBD consists of a fused silica curved 3" diameter bare-surface collection mirror, mounted close to the target, which reflects the transmitted light to a detector assembly outside the target chamber. Time integrated two-dimensional near-field images of the transmitted light are used to directly measure beam spray and deflection. The transmitted beam energy is measured by a calorimeter and a fast photo-detector. We observe a reduction of the beam spray when SSD is used, consistent with modeling by a fluid laser-plasma interaction code (pF3d). We further measured a decrease in beam transmission with increasing beam intensity, consistent with the onset of parametric instabilities.

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Feedout-Triggered Instability of an Expansion Wave in an Ideal Gas with Large γ*

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The feedout process transfers mass perturbations from the rear (inner) to the front (outer) surface of a laser-driven target, producing a seed for Rayleigh-Taylor growth (see [1, 2] and references therein). After breaking out at the rear surface of the target, the laser-driven shock wave is reflected from it as an expansion wave, that is, a centered rarefaction wave expanding into vacuum. A rippled rear surface gives rise to the rippled reflected expansion wave [1, 2]. Although a rippled centered rarefaction wave expanding into a finite pressure is unstable (the displacement amplitude of its trailing edge grows linearly with time, see [3, 4]), this instability is not seen in a rippled expansion wave – the displacement amplitudes of its leading and trailing edges remain constant as it propagates. Surprisingly, as first noticed in [1], the mass variation amplitude in the rippled expansion wave can experience an unlimited power-law secular growth if the gas γ is sufficiently high.

In the this work we derive an exact asymptotic formula for the late-time evolution of mass variation at $\gamma > 3$,

$$\frac{\delta m}{\delta m_0} \cong -\frac{2}{(\gamma-1)^4}\left[2(\gamma-1)^2 + (\gamma-3)\sqrt{2\gamma(\gamma-1)}\right]\Gamma\left(\frac{2}{\gamma-1}\right)\left[\frac{\gamma+1}{\gamma-3}(kat)^2\right]^{(\gamma-3)/2(\gamma-1)},$$

where $\delta m_0 = \rho_0 \delta x_0$ is the pre-shock mass modulation amplitude at the rippled rear surface of the target, $k = 2\pi/\lambda$ is the ripple wavenumber, and a is the speed of sound in the shocked fluid. This is a rare example of a hydrodynamic instability whose law of growth is explicitly determined by the equation of state of the fluid. We discuss the physics behind this instability and present examples of its growth obtained in 2-D hydro numerical simulations.

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* A. L. V. and N. M. are supported by the U. S. Department of Energy, J. G. W. by the Ministry of Educacion y Ciencia and Concejo de Comunidades de Castilla La Mancha, Spain.

Effects of Nonuniform Illumination on Implosion Asymmetry in Direct-Drive Inertial Confinement Fusion

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Capsule-areal-density (ρR) asymmetries are studied for direct-drive, spherical implosions on the OMEGA laser facility. Measurements of copious 14.7-MeV protons generated from D^3He fusion reactions in the imploded capsules are used to determine ρR. As they pass through the plasma, these protons lose energy, and this energy loss reflects the areal density of the transited plasma. Up to 11 proton spectrometers simultaneously view D^3He implosions on OMEGA from different directions. While the burn-averaged and spatially averaged ρR for each implosion is typically between 50 and 75 mg/cm^2 for 20-μm plastic shells filled with 18 atm of D^3He gas, significant differences often exist between the individual spectra and inferred ρR on a given shot (as large as ~±40 % about the mean). Data indicate that these asymmetries are randomly distributed over time and space. A number of sources inherent in the direct-drive approach to capsule implosions can lead to these measured ρR asymmetries. For example, in some circumstances these asymmetries can be attributed to beam-to-beam energy imbalance when this imbalance is relatively large (~25% rms). The rms variation $\langle \delta\rho R\rangle / \langle \rho R\rangle$ for low-mode-number structure is approximately proportional to the rms variation of on-target laser intensity $\langle \delta I\rangle / \langle I\rangle$ with an amplification factor of ~ ½(C_r−1), where C_r is the capsule convergence ratio. This result has critical implications for future work on the National Ignition Facility (NIF) as well as OMEGA.

This work was performed in part at the LLE National Laser Users' Facility (NLUF), and was supported in part by the U.S. Department of Energy (contract No. W-7405-ENG-48 with the University of California Lawrence Livermore National Laboratory, Grant number DE-FG03-99DP00300, and Cooperative Agreement number DE-FC03-92SF19460), LLE (subcontract P0410025G), LLNL (subcontract B313975).

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Prefer oral presentation.

34^{th} *Annual Anomalous Absorption Conference*
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Trapping-Induced Coupling Between Langmuir and Beam Acoustic Modes: RPIC and Full PIC Simulations of Stimulated Raman Scattering*

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In this work, Stimulated Raman Scattering (SRS) of Lasers is examined using both one-dimensional Reduced PIC (RPIC) [1] and Full PIC [2] simulation codes for various laser intensities and $k\lambda_D$ values in the trapping regime. The RPIC simulations include the use of a quasi-2D model for the transverse loss of thermal electrons. The spatial and temporal evolution of the electron velocity distribution and the spectral behavior of high frequency electrostatic field in k and ω space are analyzed in detail. It is shown that wave-modified electron distributions may deviate significantly from their initial Maxwellian forms and, as a consequence, the beam acoustic mode [3] is identified in the simulations. Trapping-induced spectral chirping, i.e., a streak of enhanced power spectrum in $|E(k,w)|^2$ that exhibits a decrease in ω and an increase in k, nonlinearly couples the Langmuir branch and the beam acoustic mode. At lower $k\lambda_D$ values and a moderate laser intensity, the beam acoustic mode intersects with the Langmuir branch and results in deformed dispersion branches. At higher $k\lambda_D$ and/or as the laser intensity increases, the spectrum shows a streak broadened in frequency which downshifts as the electron distribution evolves. Detailed diagnostics of trapped electrons and spectral signatures of backward and forward SRS are presented under conditions that mimic the high temperature NIF plasma and the lower temperature regime of the TRIDENT experiments [4]. The spatial and temporal dynamics of localized back-scattered light pulses in association with the spectral chirping are discussed by DuBois *et al.* [5].

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[2] W. Daughton, et al., J. Geophys. Res., **106**, 25031 (2001).

[3] L. Yin, et al., J. Geophys. Res., **103**, 29,595 (1998).

[4] D. Montgomery, et al., presentation at this conference.

[5] D. F. DuBois, et al., presentation at this conference.

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Vlasov-Poisson and Vlasov-Maxwell Simulations of Laser-Plasma Interactions Using Parallel Codes*

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We have conducted a set of simulations on a Mac Xserve Cluster on the nonlinear evolution of KEEN waves and electron plasma waves driven by the ponderomotive force of crossing laser beams. We have used both Vlasov-Poisson and Vlasov-Maxwell codes in the presence and absence of background broadband electromagnetic noise which allows for single beam SRS without relying on the probe for a seed. The nonlinear evolution of SRS and SKS[1] (Stimulated KEEN Scattering) are examined with a view to predict some of the properties of upcoming PRI experiments on Omega and Trident.[1] We will focus on the differences in the results generated by V-P and V-M codes regarding the same processes. Long time evolution of KEEN waves, in particular, will be compared via these two descriptions.

The details of the parallelization method as well as scaling and performance measures will also be given together with our plans to scale up these runs to handle larger systems and more physics including mobile ions.

[1] B. Afeyan et al., Kinetic Electrostatic Electron Nonlinear Waves and their Interactions Driven by the Ponderomotive Force of Crossing Laser Beams, Proc. IFSA, 2003, in press.
[2]B. Afeyan, et al., Optical Mixing Generation of KEEN Waves, EPWs and Their Mutual Interactions, These proceedings, 2004.

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EM-PIC Simulations of Electron Acoustic Modes

Frank S. Tsung, B. J. Winjum, W. B. Mori, and C. Joshi* -- UCLA

Self-sustained, undamped modes at or near the electron thermal velocity have been observed both in experiments (D. S. Montgomery et al, *Phys. Rev. Lett.*, **87**, 155001 (2001).), and in 1D Vlasov simulations (B. B. Afeyan et al, Paper MO3.4, *Proceedings of the 2003 IFSA conference* (2003).). The main features of this mode are zeroth order modification to the distribution function which allows these modes to exist, and phase-space structures which are held together by the aforementioned electrostatic modes.

Using two counter-propagating lasers to set up a slow moving ponderomotive potential, we have been able to set up phase-space modifications similar to those observed by Afeyan et al. We will present 1D and 2D results using the particle-in-cell code OSIRIS, and we will discuss the connection between these simulation results to experiments done on the MARS laser at UCLA.

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Prefer Poster Session

34th Annual Anomalous Absorption Conference
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2P8

Generation and Transport of Energetic Particles in Short-Pulse High-Intensity Laser Plasma Interactions.*

B. F. Lasinski, C. H. Still, A. B. Langdon, R. P. J. Town,
M. Tabak, D. E. Hinkel, and W. L. Kruer
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We report on particle-in-cell (PIC) modeling of the generation and transport of energetic electrons and ions in short-pulse high-intensity laser plasma interactions. These issues are central to the planned diagnostic and fast ignition applications of current and future petawatt lasers. The ~MeV particle generation is modeled in our explicit PIC code, **Z3**; other aspects of our PIC modeling in this parameter regime are described in references 1 and 2. We study energetic particle generation for both normal and oblique laser angles of incidence. The role of the underdense plasma established by the laser prepulse is also investigated. Our aim is the construction of an interface between explicit PIC and implicit PIC in which the latter is used for transport modeling of these energetic particles. Specifically, we report on our progress in coupling **Z3** to the implicit code **LSP**.[3]

*This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

1. C. H.. Still, B. F. Lasinski, and A. B. Langdon, "Modeling of Short Pulse High Intensity Laser-Plasma Interactions in 2 & 3D PIC Simulations," this conference.
2. A. B. Langdon, D. E. Hinkel, B. F. Lasinski, and C. H. Still, "Spectra of Scattered and Emitted Light in Modeling of High Intensity LPI," this conference.
3. D. R. Welch, *et al*, Nucl. Inst. Meth. Phys. Res. **A 242**, 134 (2001).

34th Annual Anomalous Absorption Conference

Modeling of Short Pulse High Intensity Laser-Plasma Interactions in 2 D and 3 D Simulations.*

C. H. Still, B. F. Lasinski, and A. B. Langdon

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We report on studies of short-pulse high-intensity laser plasma interactions with our massively parallel particle-in-cell (PIC) code **Z3**. We consider oblique as well as normal angles of incidence for interactions at laser intensities of $\sim 10^{19}$ W/cm^2 for 1 μm light. Modeling is done in both two and three spatial dimensions for short pulse high intensity lasers interacting with overdense plasmas. We discuss computational issues particular to these extremely large ($\sim 3.6\times10^9$ particles) simulations in 3D. In 2D we can afford to simulate larger regions transverse to the plasma normal than in the 3D modeling. We give an overview of the tradeoffs between these configurations and in particular compare magnetic field generation and density cavity formation in the overdense plasma. Energetic particle production is presented in reference 1 and features of the scattered light are described in reference 2.

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1. B. F. Lasinski, C. H. Still, A. B. Langdon, R. P. J. Town, M. Tabak, D. E. Hinkel, and W. L. Kruer, "Generation and Transport of Energetic Particles in Short Pulse High-Intensity Laser Plasma Interactions," this conference.
2. A. B. Langdon, D. E. Hinkel, B. F. Lasinski, and C. H. Still, "Spectra of Scattered and Emitted Light in Modeling of High Intensity LPI," this conference.

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2P10

"PIC Simulations of Laser-Plasma Interactions at Intensities Relevant to NIF"

B. J. Winjum, F. S. Tsung, W. B. Mori (UCLA), A. B. Langdon, D. E. Hinkel (LLNL)

Unraveling the combination of nonlinear physics that saturates stimulated Raman scattering (SRS) under NIF type conditions is a great challenge. The physics combines multiple wave-wave interactions with wave-particle interactions. One key tool needed to meet this challenge is fully kinetic simulation models. The hope is that insight gleaned from fully kinetic models can be integrated into nonlinear fluid codes. Using the code OSIRIS, we have carried out simulations of SRS for several sets of laser and plasma parameters. In one the laser intensity is 5.6×10^{14} W/cm^2 and the plasma temperature is 1.5 keV. This corresponds to parameters used by Vu *et al.*, where a reduced PIC model was used. We get qualitative agreement between OSIRIS and RPIC. In another, the laser intensity is 1×10^{16} W/cm^2 while the plasma temperature varies from 5 to 7 keV. This corresponds to possible designs for NIF. In the third, the laser intensity is 1×10^{16} W/cm^2 while the plasma temperature is as high as 20 keV. This corresponds to conditions in a high-temperature hohlraum. In 1D simulations for the NIF conditions, the relative role of backscatter to forward scatter decreases as the plasma temperature, i.e. $k\lambda_D$, is increased. It has been found that the forward scattered light can be reflected by Brillouin scattering [D. E. Hinkel *et al.*, Phys. Plasmas **11**, 1128, (2004)]. We are exploring the evolution of Raman sidescatter and the electron distribution function in multiple dimensions and in density gradients.

Work supported by DOE NNSA.

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2E. A. Williams,et al., Phys. Plasmas 2, 129 (1995)
3*This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

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Ion Acceleration Via Ultra Intense Laser Interactions with Over and Underdense Plasmas*

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The possibility of proton acceleration from overdense and underdense laser interactions is investigated via particle-in-cell (PIC) simulations using the code OSIRIS. The parameters for the simulations are chosen to correspond to an intense laser interacting with a thin metal foil (the overdense case) or a uniform gas (underdense case). In both cases, high-Mach number electrostatic shocks are formed that can accelerate the ions to high energies. In addition to the shocks, time dependent ambipolar electric fields arise due to the free expansion of strongly heated electrons. Both of these mechanisms, shock acceleration and free expansion acceleration, are observed in the simulations. For both the overdense and underdense cases, high Z ions are added. In some cases these ions gain energy in excess of 1 GeV. The use of multiple laser pulses and target configurations is also being investigated.

*Work supported by LLNL and DOE.

Demonstration of > 100 times amplification of short laser pulses by Raman backscattering in plasma

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Current ultrashort pulse lasers rely on the chirped-pulse-amplification (CPA) scheme. This very successful method is limited at ultrahigh intensities mainly due to the damage threshold of gratings in the final compressor. Amplification and compression of laser pulses in plasma has been proposed in order to overcome this limit since plasma has no thermal damage threshold. Employing plasma as the gain medium in a single-pass configuration also dramatically decreases the cost and size of the system.

In this presentation we report an amplification > 100 of short laser pulses via resonant Raman scheme in a gas jet plasma. This indicates the practical possibility of the Raman scheme in plasma. With a broadband seed we demonstrate resonance peaks in the spectra corresponding to various plasma densities. It is also observed that the spectral width of the amplified pulse broadens as the amplification increases. Indirect measurements of the duration of the amplified pulses reveal the appearance of shorter pulses at higher amplification. Theoretical modeling shows a qualitative agreement with the measurements, and the effects of laser intensities and the plasma conditions on the amplification process will be discussed.

This work was supported by DOE and DARPA funds.

Nonstationary effects in the nonlocal closure of transport equations

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The linear nonlocal hydrodynamics of Ref. [1] has been generalized to include time dependence in the nonlocal kernels of electron transport relations. These frequency dependent transport coefficients are necessary in studies of Langmuir wave dispersion relation for the arbitrary electron collisionality. But the nonstationarity is also important in the low frequency plasma response to a steep temperature gradient which corresponds to temperature variations on the scale of the electron mean free path. We have defined different regimes of linear transport relations with respect to nonstationary and nonlocal responses. We have found the characteristic relaxation time to the stationary nonlocal transport models which are usually implemented in the hydrodynamical simulations. The new nonlocal and nonstationary transport theory has been applied to the description of plasma fluctuations and the derivation of a dynamical form factor. Based on this theory we discuss the Thomson scattering cross-section in collisional plasmas with an application to x-ray Thomson scattering measurements.

[1] V. Yu. Bychenkov, W. Rozmus, V. T. Tikhonchuk and A. Brantov, Phys. Rev. Lett., **75**, 4405 (1995)

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Plasma Slab Radiating Pseudo-Cavity Mode in SRS-like Behavior for Frequency Difference Less than the Plasma Frequency: KEEN-type mode in Relativistically Hot Plasma

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Vlasov-Maxwell simulations on a flat-topped plasma slab were seen by Nikolic et al. [1] to give transient SRS-like behavior, even for n/nc = 0.6 (where there is no weakly damped small-amplitude plasma wave perturbation), but with frequency shift (roughly $\omega_0 - \omega_p$) considerably less than the plasma frequency ω_p. From our own Vlasov-Maxwell simulations at Nancy an explanation has emerged. The explanation for this behavior (at least for relativistically strong fields and relativistically hot plasmas) is that there is a "radiating pseudo-cavity" electromagnetic mode with relatively low loss for the slab at a frequency close to ω_p, and this allows the initial excitation of the KEEN waves at a well-defined frequency ($\omega_0 - \omega_p$). (The KEEN wave characteristics have been discussed by Afeyan et al. [2]). Whether this behavior will persist when the edge density gradients become less than c/ω_p remains to be seen.

[1] L. J. Nikolic et al., Phys. Rev. E, 66, 036404 (2002)
[2] B.B. Afeyan et al. 33rd AAAC (2003), [1] B. B. Afeyan, K. Won, V. Savchenko, T. W. Johnston, A. Ghizzo, P. Bertrand, Paper # 238, IFSA 2003 (and ms submitted to *Phys. Rev. Lett.* 2004).

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Enhanced Plasma Collisionality, Part II*

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In a variety of experiments conducted at Sandia National Laboratories on the Saturn pulsed-power, Z-pinch generator, an exceptionally large amount of x-ray emission was observed. Canonical 1-D radiation-hydrodynamic modeling of these experiments, which employs Braginskii transport coefficients, is incapable of providing the energy inputs to the imploding Z-pinch plasmas that are greater than or even equal to the x-ray energy outputs that were recorded in the experiments. The energy inputs are in deficit by factors of 2 to 4. Much more Ohmic heating was needed in the modeling of these experiments than is conventionally calculated, which implies that the plasma is much more collisional than is calculated from classical kinetic theory. Moreover, phenomenological modeling of the Saturn experiments has shown that several orders of magnitude increases in the electrical resistivity are needed and that these increases are closely correlated with the rapid rise in the x-ray output that occurs as the plasma begins its assembly on axis. Due to the long range nature of the Coulomb force[1], elastic scattering in a plasma medium is different from electron-electron and electron-ion scattering in free space, and enhancements to the Rutherford scattering cross section are possible because of other interactions that take place in the plasma medium. Langmire[2], for example, speculated that couplings to the radiation field, which occur during electron scattering events, were responsible for the much shorter mean free paths that he had measured in some early electrical discharge experiments than could be explained by the electron-electron or electron-atom collision cross sections that he had also measured. In this talk, we apply the methodology described in Reference 3 to investigate the possibility that higher than binary-order collision theory has some bearing on the problem.

1. L. P. Kadanoff and G. Baym, "Quantum Statistical Mechanics", W. A. Benjamin, Inc., New York, Chap. 12, (1962).
2. I. Langmuir, Phys. Rev., **26**, 585 (1925).
3. D. F. DuBois, "Lectures in Theoretical Physics", Vol. IX C, ed. by W. E. Brittin, A. O. Barut, and M. Guenin, p. 469 (1966).

*Work supported by Sandia National Laboratories and DTRA
**Berkeley Scholars Inc., Beltsville, MD 20705.

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An efficient explicit numerical scheme for hot fusion particle slowing-down in the Fokker-Planck formalism

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In preparation for the numerical simulation of ignition and burn in ICF targets with our Fokker-Planck code "FPion"[1], efficient methods are investigated for the numerical treatment of collisions of a distribution of hot α particles in the presence of the much colder bulk DT plasma. The Coulombian slowing-down and diffusion terms in velocity space induced by the cold plasma are both very localized and highly anisotropic, which makes implicit schemes very ill-conditioned and thus not easily amenable to iterative solving methods such as conjugate-gradient or the like. On the other hand, the simpler Jacobi iteration method can be shown to be equivalent to explicit time-stepping, and thus impractical when locally high values of the diffusion tensor constrain the time step to very small values. The high anisotropy also makes the use of the same ADI scheme as for the bulk plasma questionable.

We thus developed a Locally Split-Step Explicit (LSSE) algorithm for efficiently solving a multi-dimensional diffusion equation involving a highly-inhomogeneous diffusion tensor κ. This algorithm performs time-step splitting only in cells where it is actually needed due to locally high values of the diffusion tensor, so as to satisfy the time-step condition for stability

$$\frac{\delta t}{\delta v^2}\mathrm{Tr}(\kappa) \leq \frac{1}{2}$$

on a per-cell basis. The computational cost of this scheme (number of operations N_{op} required for advancing the system over a time Δt, using an overall time step δt) in the case of a Coulombian-type diffusion ($\kappa(v) \sim 1/v$) will be shown to be the sum of two parts :

$$N_{op}(\Delta t, \delta t, N, v_{max}) = O\left(\frac{\Delta t}{\delta t} N \mathrm{Log} N\right) + O\left(\frac{\Delta t}{\tau_c(v_{max})} N^2\right)$$

where N is the number of cells in the discretized velocity space, v_{max} is the largest value of the discretized velocity and $\tau_c(v)$ is the slowing-down time for a particle with velocity v. Put in other words, the LSSE scheme, when used to advance the simulation of a thermonuclear fusion plasma over the α particle slowing-down time, is expected to need about as many operations ($O(N^2)$) as a **single** step of a straightforward implicit scheme.

[1] O. Larroche, Eur. Phys. J. D **27**, 131 (2003).

A High-Resolution Neutron Spectrometer for ρR_{fuel} and T_i Measurements at OMEGA and the NIF

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A method for determining the ρR_{fuel} of cryogenic deuterium–tritium (DT) plasmas involves the measurement of the energy spectrum and yield of elastically scattered, primary neutrons. A novel spectrometer has been designed to accomplish this at OMEGA and the NIF, using scattered neutrons in the energy range of 7 to 10 MeV to determine ρR_{fuel} and primary neutrons to measure T_i. The instrument is based on a magnetic spectrometer with a conversion foil to produce charged particles at nearly forward scattered angles. Initially, a thin CH foil in combination with CR-39 track detectors positioned in the focal plane of the spectrometer will be used to detect recoil protons scattered by 14.1-MeV primary neutrons. In later implementation, CVD-strip detectors or scintillators may be used to detect deuteron recoils for ρR_{fuel} measurements. A large dynamic range ($>10^6$) will allow operation at yields as low as 10^{12}. This will allow ρR_{fuel} measurements of warm and cryo DT targets at OMEGA and fizzle and ignited cryo DT targets at the NIF. Using *LASNEX* and neutron transport calculations, the signal-to-noise (S/N) ratio is estimated to be of the order 100 for measurements of cryo DT targets at OMEGA and the NIF, irrespective of the detection scheme.

This work was performed in part at the LLE National Laser Users' Facility (NLUF), and was supported in part by the U.S. Department of Energy (contract No. W-7405-ENG-48 with the University of California Lawrence Livermore National Laboratory, Grant number DE-FG03-99DP00300, and Cooperative Agreement number DE-FC03-92SF19460), LLE (subcontract P0410025G), LLNL (subcontract B313975).

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Prefer poster presentation.

Self-organization of a plasma due to 3D evolution of the Weibel instability

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The nonlinear evolution of the Weibel instability is studied by using three dimensional particle-in-cell simulations. The instability is driven by the anisotropy in the electron energy distribution. After first saturating due to a reduction in temperature anisotropy, the instability evolves to a quasistationary state which includes a single mode circularly polarized long wavelength magnetic field perturbation and a finite degree of temperature anisotropy. The nonlinear stability of this state is explained by periodic variations of the temperature anisotropy axis. This explanation follows from the analytical solution to the equations of vortex electron anisotropic hydrodynamics which describe a nonlinear evolution of the long-wave Weibel instability.

The frequency and damping of ion acoustic waves in semi-collisional, two-species plasma

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The dispersion properties of ion acoustic waves are sensitive to the strength of ion-ion collisions in multi-species plasma in which the different species usually have differing charge-to-mass ratios. The modification of the frequency and damping of the fast and slow acoustic modes in a plasma composed of light (low Z) and heavy (high Z) ions is considered. In the fluid limit where the light ion scattering mean free path, λ_{lh} is smaller than the acoustic wavelength, $\lambda = 2\pi/k$, the interspecies friction and heat flow carried by the light ions causes the damping.[1] In the collisionless limit, $k\lambda_{lh} >> 1$, Landau damping of the light ions provides the dissipation.[2] In the intermediate regime when $k\lambda_{lh} \sim 1$, the damping is at least as large as the sum of the collisional and Landau damping. Specifically, mixtures of Xe and H will be considered with the concentration of Xe varied from 1% to 10% by atom. Acoustic wave damping in hydrocarbon (CH) plasmas is also shown to be affected by interspecies collisions.[3]

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[1]Bychenkov et al., PRE 51, 1400 (1995); E.M. Epperlein, *et al.*, PRE**49**, 2480 (1994)
[2]E.A. Williams, *et al.*, Phys. Plasmas **2**, 129 (1995)
[3]Work performed under the auspices of the U.S. Department of Energy by University of Calfornia, Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48 and U.S. D.o.E. Contract No. DE-AC02-76-CHO-3073.

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Statistical Model for Laser Beam Multiple Scattering on Self-Induced Density Fluctuations

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Recent experiments show that propagation of a randomized laser beam at relatively low intensities, well below the critical power for the filamentation instability, through a very low density plasma enhances spatio-temporal beam smoothing. It has been suggested that the coherence loss is due to multiple scattering of the transmitted light on self-induced density fluctuations. We propose a statistical model for this phenomenon.

Considering a spatially inhomogeneous laser as a driving source for plasma fluctuations, we first discuss the dynamics of density perturbation formation. We describe analytically the transverse density profile evolution for one- and two-dimensional cases with a simple wave model. We analyze the influence of the laser temporal coherence on these fluctuations. Furthermore, a statistical description of the density fluctuations is proposed using the density correlation function. In the Gaussian limit, we obtain the spectrum for plasma perturbations. It shows the importance of correlations between the propagating humps ($\omega = \pm c_s k$), but also between humps and stationary holes ($\omega = \pm c_s k/2$).

Finally we derive a propagation equation for the correlation function of the electric field that characterizes the laser coherence properties. We show that the spatial transverse coherence length is modified during the propagation and also that a temporal smoothing appears. These effects become important after a certain distance, which depends on the laser intensity, the plasma density and the temperature. Numerical calculations performed using the three-dimensional laser-plasma interaction code PARAX confirm our analysis and suggest a coupling between multiple scattering and forward stimulated Brillouin scattering.

Wednesday, May 5, 2004

Daily Program

8:00 AM - 8:45 AM	**Continental Breakfast**
8:45 AM	**Conference Begins**
8:45 AM -10:25 AM	**Oral Session 3**
10:25 AM -10:55 AM	**Break**
10:55 AM - 12:55 PM	**Oral Session 3 Cont**
7:00 PM - 9:00 PM	**Banquet**
9:00 PM	**E. M. Campbell,** ***Banquet Speaker***

Oral Session 3

A. J. Schmitt, Chair

Transition from Classical RM Instability at Embedded Material Interface to Ablative RM and RT Growth

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The seeds for the Rayleigh-Taylor (RT) instability in laser-accelerated targets come from a variety of laser beam and target imperfections. If a target is designed with material interface(s) embedded into it, then interaction of the first shock launched by the ablative pressure with the interface(s) triggers a classical Richtmyer-Meshkov (RM) growth there. We study the case of a single rippled light-to-heavy material interface in planar geometry. As the RM growth starts at the interface, a rippled transmitted shock wave carries the perturbations to the planar rear surface, and after breakout gets reflected from it as a rippled expansion wave [1] which propagates through the coherent perturbation field left by the passage of the rippled shock. At the same time, perturbations come to the planar ablation front from the rippled reflected shock wave. Its breakout at the ablation front sends a reflected rippled rarefaction wave back to the material interface, and triggers the growth of an ablative RM instability. In this case the ablative RM instability is started in a non-conventional heavy-to-light regime because the perturbation comes from the heavier fluid (compare to the regular light-to-heavy case [2]). Both the ablative RM instability and the sonic mass flow behind the trailing edge of the rippled rarefaction wave reflected from the ablation front reverse the positive growth of mass modulation amplitude due to the classical RM instability at the original material interface. As a result, lateral mass flow in the vicinity of the ablation front accumulates more mass near the minima of the areal mass of the pre-shocked target. When the sound wave signaling the decompression arrives from the rear surface to the ablation front, the RT growth starts in the negative direction, as first predicted in our simulations [3], and in contrast with the regular cases of ablative RT growth started by either ablative RM instability [2] or feedout [4]. We present the results of the theory and numerical simulations, and compare them to the data obtained in recent hydrodynamic experiments with plastic-foam targets on Nike KrF laser at NRL.

[1] A. L. Velikovich and L. Phillips, Phys. Fluids **8,** 1107 (1996); J. G. Wouchuk, R. Carretero, Phys. Plasmas **10**, 4237 (2003).
[2] V. N. Goncharov, Phys. Rev. Lett. **82**, 2091 (1999); Y. Aglitskiy *et al.*, Phys. Rev. Lett. **87**, 265001 (2001).
[3] N. Metzler *et al.*, Phys. Plasmas **10**, 1897 (2003).
[4] A. L. Velikovich *et al.*, Phys. Plasmas **8**, 592 (2001); Y. Aglitskiy *et al.*, Phys. Rev. Lett. **87**, 265002 (2001).

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Observation of Classical Richtmyer-Meshkov Instability Feeding Ablative Rayleigh-Taylor Growth in Planar Plastic Targets*

Y. Aglitskiy,[a] M. Karasik, V. Serlin, S. P. Obenschain, A. L. Velikovich, N. Metzler,[a,b] A. N. Mostovych, A. J. Schmitt, J. H. Gardner,[c] J. Varadarajan,[d] and T. Walsh[d]

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We report new results of hydrodynamic experiments performed on KrF Nike laser at NRL as a part of our ongoing effort to create a database for benchmarking computer codes in cases that allow *ab initio* simulations [1]. We observed a classical Richtmyer-Meshkov growth at the shocked embedded foam/plastic interface evolving into an ablative Rayleigh-Taylor growth. Our advanced two-slab targets consisted of a RF foam layer (thickness 130 μm, density 0.33 g/cm^3) separated by a single-mode 2-D sinusoidal interface (wavelength 30 μm) from a 30 μm thick solid plastic layer. They were manufactured for these experiments at Schafer Laboratories and featured a full-contact, classical rippled foam/plastic interface (in earlier experiments on RM instability in plastic/foam targets, rippled plastic surface was in contact with a planar foam slab only at its peaks [2]). The targets were irradiated from the foam side by the Nike pulses (wavelength 248 nm, pulse duration 4 ns, intensity 50 TW/cm^2, with and without a 3.5 ns long foot preceding the main pulse, at 5% of its peak intensity). When the planar shock wave launched by the ablative pressure reached the foam-plastic interface from the lower-density side, it triggered a classical RM growth with reflected shock wave. The evolution of mass variation in the target was recorded with our monochromatic x-ray imaging system coupled to a streak camera [1]. In agreement with our simulations [3], a linear growth of mass modulation amplitude in positive direction characteristic of the RM instability with reflected shock was observed to continue until the amplitude reached a peak value, after which its variation changed direction and gradually evolved into the ablative RT growth with a reversed phase. Both the observed timing and amplitude of the peak scaled as predicted when the laser pulse shape was modified by adding a foot.

[1] Y. Aglitskiy *et al.*, Phys. Plasmas **9**, 2264-2276 (2002).
[2] S. G. Glendinning *et al.*, Phys. Plasmas **10**, 1931 (2003).
[3] N. Metzler et al., Phys. Plasmas **10**, 1897 (2003).

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An Empirical, Dynamic Mix Model for ICF Implosions

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Mix is a vital concern in ICF because it can quench the nuclear burn in the hot spot prematurely, or even extinguish it entirely. Understanding the timing and extent of mix under different conditions will be an important step toward mitigating its effects. A new empirical, dynamic mix model is under development that will be tightly constrained by nuclear burn history measurements of two types of hydrodynamically equivalent implosions. DD and D^3He burn histories measured from D^3He filled, CH-shell targets look primarily at the core of the implosion, whereas DD and D^3He burn histories from pure-^3He filled, CD-shell targets give a clearer view of the shell and the mix regions. A summary of the common features of the measurements and an outline of the mix model development will be presented.

This work was performed in part at the LLE National Laser Users' Facility (NLUF), and was supported in part by the U.S. Department of Energy (contract No. W-7405-ENG-48 with the University of California Lawrence Livermore National Laboratory, Grant number DE-FG03-99DP00300, and Cooperative Agreement number DE-FC03-92SF19460), LLE (subcontract P0410025G), LLNL (subcontract B313975).

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Prefer oral presentation.

Utilizing Emission Spectroscopy to Study the Time Dependence of Interface Mix*

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In recent ICF experiments, we imploded both 15 and 3 atm DD filled CH micro-balloons 860 microns in diameter with a 19 micron thick wall. This wall included a 0.1 micron thick layer of 3.8% titanium-doped plastic on the inner wall surface as a time-dependent spectroscopic probe of mix. These implosion experiments provided very interesting time-resolved spectral data that show definite evidence of mix but still does not agree fully with the modeled spectra. With the simulated yield values matched to the experimental yield data, we observed stronger line emission from the hydrogen-like titanium alpha line over the time of emission then modeled in the spectral post-processed output of a Lagrangian 1D hydrodynamics simulation utilizing the Scannapieco and Cheng multi-fluid interpenetration mix model [1]. This difference in emission behavior is an indication of an experimental mix profile where more titanium is being exposed to hotter fuel conditions then predicted by the simulation utilizing this mix model. With this time-resolved spectral data, we should now be better able to place constraints on and modify, if necessary, the mix model in question.

[1] Scannapieco, A.J. and Cheng, B.L., Physics Letters A 299, no. 1, p 49-64.

*This work was performed under the auspices of the Department of Energy, DOE contract No. W-7405-ENG-36.

Simulations and Experiments on Adiabat Shaping by Relaxation

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Adiabat shaping by relaxation has been proposed as a method for stabilizing inertial confinement capsule implosions. The relaxation method consists of a low-intensity prepulse followed by a period of laser shutoff and the main pulse. This shutoff period allows the outer-shell portion to relax, creating a monotonically increasing density profile. The adiabat profile is shaped when the main pulse is turned on and the main shock travels up the relaxed density profile. As the main shock encounters increasing densities, the resulting post-shock entropy decreases and the shell adiabat develops a profile that exhibits its maximum at the ablation front and minimum on the inner shell surface. The high entropy at the ablation front leads to higher ablation velocities, thus significantly reducing the Rayleigh–Taylor growth rates of short-wavelength modes.

Adiabat-shaping implosion experiments to carry out on the OMEGA laser for CH and cryogenic capsules have been designed and simulated with the 2-D code *DRACO*. Results from recent plastic-shell implosions on the OMEGA laser system as well as the results of the 2-D simulations seem to confirm suppression of short-wavelength-mode growth due to adiabat shaping by relaxation.

This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC03-92SF19460, the University of Rochester, and the New York State Energy Research and Development Authority. The support of DOE does not constitute an endorsement by DOE of the views expressed in this article.

Prefer oral presentation

Polar-Direct-Drive Experiments on OMEGA

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The polar direct drive (PDD) approach to ignition on the NIF uses just the baseline indirect-drive ports (at angles of 23.5° to 50° from the vertical) with the beams repointed toward the equator. This concept is being examined on OMEGA with directly driven implosions using the subset of 40 beams whose ports have angles from 21° to 59° with respect to the vertical (an axis with five-fold rotational symmetry).

The experiments reported here used standard OMEGA implosion targets (20-μm-thick CH shells of 865-μm diameter filled with 15 atm of deuterium), driven by 1-ns flat laser pulses with 400 J per beam. The rings at 21°, 42°, and 59° were repointed toward the equator by 90 μm, 180 μm, and 180 μm, respectively, measured perpendicular to the beam axes. The repointings were chosen on the basis of self-consistent ray-tracing calculations using the 2-D hydrodynamics code *SAGE* and were similar to those used in earlier PDD experiments.[1] Six of the remaining 20 beams were used for x-ray backlighting. Diagnostics included framed x-ray imaging of the imploding target shell, streaked x-ray imaging of the target self-emission, time-integrated x-ray microscope imaging of the compressed core, and a variety of nuclear diagnostics.

Supporting experiments were also carried out. Sixty-beam implosions at 2/3 the normal energy, with all beams pointed at the target chamber center, showed that the 40-beam PDD implosions resulted in a yield reduction of a factor of 2.7. The 60-beam irradiation of 1600-μm-diam solid targets with the beams repointed in a symmetric way was used to study the angle dependence of absorption.

The experiments were modeled in both one and two dimensions. The absorption results were consistent with full ray-trace modeling, and the imploding trajectory was consistent with predictions. The imploding shell showed a small deviation from sphericity (slower at the equator), consistent with *SAGE* predictions.

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1. S. G. Glendinning and G. Kyrala, private communications (2003).

Prefer oral presentation.

Detailed hydrodynamics simulations of 2ω laser-plasma interaction experiments*

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Recent green light (2ω) gasbag experiments on the Helen and Omega laser facilities examined stimulated Raman backscatter (SRS) from long (≈2 mm), CH plasmas similar to what might be encountered in a NIF ignition hohlraum. We present detailed analyses of these experiments performed with the multiphysics code HYDRA. We find that by post-processing the results of 2-D radiation-hydrodynamics simulations, we are able reproduce many features of the experimental data. In the single beam Helen gasbag experiments, laser propagation and interaction occurred simultaneously. At low initial density ($n_e < 0.1$ n_c), we recorded time-resolved SRS spectra that are constant in wavelength vs. time. The spectra broaden and tilt towards λ_0 (with time) as initial gasbag density increases. The time-resolved SRS spectra seemingly show evidence of filamentation; however, gain spectra post-processed from the HYDRA results show that the experimental SRS spectra can be explained solely by bulk hydrodynamics. The heating and expansion of the laser channel results in an axial density gradient that produces SRS light in a broad wavelength range. The best agreement with experiments is obtained when HYDRA is run with a recently-installed nonlocal thermal electron transport model.

In the multi-beam Omega gasbag experiments, the 2ω interaction beam was fired through a pre-formed plasma. The SRS streak spectra show a rapid decrease in wavelength at a time corresponding to heater beam shutoff. For these experiments, it is necessary to simulate the aluminum washer supporting the gasbag skin, as electron conduction to the washer rapidly cools the plasma. Gain spectra post-processed from the HYDRA results successfully reproduced the experimental SRS streak spectra. In addition, the simulated electron temperature agrees well with Thomson scattering measurements from inside the gasbag. The simulated plasma property profiles have been used with transmission measurements to reduce the uncertainty in the measured total backscatter. The simulation and analysis methodology established here can be used on upcoming experimental campaigns.

* This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Non-LTE Speed of Sound, Irreversibility, and Thermodynamic Consistency

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The speed of sound is a quantitatively important parameter in ICF applications such as the timing of shock waves in implosions and laser–plasma interaction and material-property experiments. The speed of sound in a radiating plasma is obtained from a fully self-consistent model of optically thin radiation based on nonequilibrium thermodynamics, including the irreversible loss of radiated energy. The speed of sound is altered by familiar non-LTE (not in local thermodynamic equilibrium) effects that significantly alter the atomic state and radiative emissivity of the plasma. Sound waves are a hydrodynamic phenomenon, so their behavior reflects non-LTE modification of the equation of state, as well as modifications of the radiative properties of the plasma. The model is greatly simplified by including only the recombination radiation from a single ionization transition between two ionization species. In spite of its simplicity, this model is applicable to more-complete collisional-radiative models, allowing the importance of non-LTE effects on the sound speed to be assessed over a broad range of conditions. The thermodynamic consistency of the radiation model and the equation of state is an explicit constraint of the thermodynamic framework of this model. Nevertheless, the equation of state and the emissivity can be adjusted independently to show the sensitivity of the speed of sound to a small thermodynamic inconsistency, providing an estimate of the potentially important effects of mismatched equations of state and opacity/emissivity models in hydrodynamic simulations in general.

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Prefer oral presentation

Stopping and Scattering of Directed Energetic Electrons in High-Temperature Hydrogenic Plasmas

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From fundamental principles, the interaction of directed energetic electrons with a high-temperature hydrogenic plasma is analytically modeled. The randomizing effect of scattering off both plasma ions and electrons is treated. For electron energies of less than 3 MeV, electron scattering dominates. The net effect is to reduce the penetration from 0.53 to 0.35 g/cm^2 for 1-MeV electrons in a 300-g/cm^3 plasma at 5 keV. These considerations are relevant to "fast ignition," to fuel preheat for inertial confinement fusion, to relativistic astrophysical jets, and to many high-energy laser–plasma experiments for which $Z \sim 1$ and $\gamma < 10$. For $Z > 1$, ion scattering always dominates, which, we suspect, is the reason previous workers did not consider the effects of electron–electron scattering in plasmas.

To experimentally explore the importance of electron scattering in hydrogen, we are proposing an experiment in which monoenergetic electrons (0.1 MeV $< E <$ 1.0 MeV) would scatter off a thin layer of D_2 or H_2 ice. The ice thickness would be between 100 and 1000 μm, the appropriate thickness depending on the incident electron energy. Although the stopping-power and scattering calculations for solid D_2 ice have some differences from the plasma case, albeit of direct relevance to the electron preheat problem, we do anticipate that the relative importance of the electron-to-electron and electron-to-ion scattering terms should be quite comparable for both hydrogenic plasmas and ice. Part of our ongoing work is to establish the validity of this hypothesis.

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* Also Visiting Senior Scientist at LLE.

Prefer oral presentation.

Developing a Laser Raytrace Package in an Eulerian AMR radiation-hydrodynamics code (IAGO)*

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SAIC is working with Los Alamos National Lab (LANL) to develop an ASCI code capable of ICF calculations -- a 3T superset of the 2 temperature radhydro code RAGE. Our raytrace algorithm uses (bi/tri) linear representations of both electron density and gradients of electron density in order to smoothly refract rays from one zone to another. Every processor loops over the full list of rays (assumed to be of order thousands), pushing the ray through zones on processor and re-syncing at the end of the loop, relooping until no significant energy remains in rays still in the mesh. Energy is continuously attenuated via Bremsstrahlung. A "dumpall" construct currently mocks up instabilities and deposits energy by trickling it into zones over time in order to avoid dumping too much of a ray's energy into too small of an AMR zone. Results will be reported on the 2-D and 3-D modeling of some thin-walled hohlraums.

*This work was performed under the auspices of the Department of Energy by the Los Alamos National Laboratory under contract W-7405-ENG-36, and by Science Applications International Corporation under a subcontract to LANL.

34th Annual Anomalous Absorption Conference
Gleneden Beach, Oregon
May 2 -7, 2004

Beam deposition model for energetic electron transport in Inertial Fusion*

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Our model for non local deposition of energetic electrons[1] has been improved, compared routinely to our newly implemented delocalization model of Epperlein and Short (ES)[2] and more significantly compared to experimental results obtained at LLE[3]. Detailed comparisons with flux-limited solutions, delocalization model and Fokker-Planck results when available will be shown and have made us more aware of which physical features an electron transport model should have. These detailed comparisons will also show how the various models fail in emulating a realistic transport scheme. For instance, both a flux-limit model and the ES model frequently tend to generate heat fronts whose width is at least an order of magnitude smaller than the mean-free path.
Since our model is relatively simple in terms of modeling the whole physics of electron transport (steady-state, mono-directional beam in particular), it includes several parameters- which are not free however- and whose sensitivity will be addressed. As the physics and numerics of our model is still being under development, comments from the audience are appreciated and will be duly noted, with no guarantee that they will be acted on in any further development.

also, with RSI
* ARTEP Inc., Columbia,Md

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2. E.Epperlein and R.W.Short, Phys. Fluids **B3**, 3092, 1991
3. A.Sunahara, J.Delettrez et al, Phys. Rev. Lett. **91**, 095003, 2003

*This work was supported by the U.S. Department of Energy.

Thursday, May 6, 2004

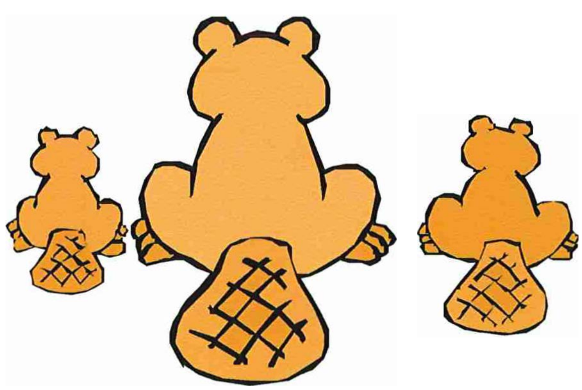
Daily Program

8:00 AM - 8:45 AM	**Continental Breakfast**
8:45 AM	**Conference Begins**
8:45 AM -10:25 AM	**Oral Session 4**
10:25 AM -10:55 AM	**Break**
10:55 AM -12:55 PM	**Oral Session 4 Cont**
7:30 PM -8:30 PM	**Invited Session 4**

Dr. T. W. Johnston

Plasma Physics at the Anomalous Absorption Conference, as seen by a plasma physicist newly returned to the fold

8:30 PM -11:00 PM	**Poster Session 4**



Oral Session 4

W. Seka, Chair

34th Annual Anomalous Absorption Conference
Gleneden Beach, Oregon
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Pump Side-Scattering in Ultra-Powerful Backward Raman Amplifiers

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Extremely large laser power might be obtained by compressing laser pulses through backward Raman amplification (BRA) in plasmas. Premature Raman backscattering of a laser pump by plasma noise might be suppressed by an appropriate detuning of the Raman resonance, even as the desired amplification of the seed persists with a high efficiency. In this paper we analyze side-scattering of laser pumps by plasma noise in backward Raman amplifiers. Though its growth rate is smaller than that of backscattering, the side-scattering can nevertheless be dangerous, because of a longer path of side-scattered pulses in plasmas and because of an angular dependence of the Raman resonance detuning. We show that side-scattering of laser pumps by plasma noise in BRA might be suppressed to a tolerable level at all angles by an appropriate combination of two detuning mechanisms associated with plasma density gradient and pump chirp.

Nonlocal electron transport*

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We want a model for nonlocal electron transport that is suitable for use in radiation-hydrodynamics simulations of laser-plasmas, because often the mean-free-path of the energy transporting electrons is not short compared to the scale-length of the temperature, and classical transport theory fails. We have shown that the multi-group, in energy, diffusion, in space, Fokker-Planck transport equation governs the physics of interest, but we have not accomplished either its implementation as, or its reduction to, a robust and efficient model. Our multi-group diffusion model is not efficient, and our reduced integral equation model for the evolution of the temperature due to the nonlocal heat flux is not robust.

Here we describe work towards a robust integral equation model for the temperature evolution. To this end it has been shown that according to the linearized transport equation, the decay rate of short wavelength temperature perturbations is approximately proportional to $k = 2\pi/\lambda$, while the thermal decay rate is approximately independent of k according to the linearized integral equation model. Then its poor description of the decay of short wavelength temperature perturbations is seen to contribute to the lack of robustness of the integral equation model.

The scaling of the thermal decay rate according to the integral equation model is determined by that of the nonlocal propagator that multiplies the temperature gradient in the integral for the nonlocal heat flux. Then it has been supposed that the linearized transport equation implies a qualitatively different nonlocal propagator than that in hand.

We report investigations of the linearized multi-group diffusion transport equation that show that it is including the time dependence of the Maxwell-Boltzmann distribution in the equation for the perturbation distribution δf that reconciles our understanding of the linearized transport equation and the integral equation model via the k-scaling of the thermal decay rate. Finally, we show the associated new time dependent integral equation model for nonlocal electron transport that uses the familiar nonlocal propagator.

*This work was performed under the auspices of the U.S. Department of Energy by University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Controlling filamentation in 300eV 2ω (green) ignition target designs

Larry Suter, A. Bruce Langdon, E. A. Williams, S. Glenzer, J. Moody LLNL

For several years we have been exploring the possibility of using green (2ω) light for indirect drive ignition on NIF. One concern about 2ω light, compared to 3ω light, is that it is more liable to filament. Numerical and analytic studies indicate that filamentation will begin to occur with NIF beam geometry when the filamentation figure of merit (FFOM)=$I\lambda^2$(ne/nc)/(3keV/Te) exceeds 5-10x10^{12}. This FFOM would scale like λ^4 given a target of fixed mass density, intensity and electron temperature. Thus, in going from a 3ω ignition design where the FFOM is ~3x10^{12} to the same target operating at 2ω, we might expect the FFOM to jump about a factor of $(3./2.)^4$=5, placing it above the threshold for filamentation. However, detailed numerical simulations of the targets indicate that the increase in the FFOM can be much less when changing to green. This is because the plasma temperature is somewhat higher with 2ω, which allows the hohlraum blowoff plasma to develop the same hydrostatic pressure with a somewhat lower plasma mass density. This effect lowers the blue-to-green increase in FFOM to about a factor of three. Further reductions in the FFOM can be gained by changing the composition of the plasma filling the hohlraum. For example, simulations have previously indicated that it is possible to replace the He gas in a 2ω ignition hohlraum design with 1 mg/cc SiO_2 foam (this exists) or GeO_2 foam (doesn't yet exist) and still maintain drive and symmetry. The effect of these changes on the bulk plasma conditions is to make the electron temperature even higher and the mass density lower. In these designs the FFOM is about 2-2.3X the FFOM in the original 3ω design. Finally, if we invoke polarization smoothing, which pF3D simulations indicate effectively reduces the FFOM by another factor of 1.6, we end up with a 2ω, 300eV with a FFOM that is ~50% higher than the original 3ω design filled with He and less than the filamentation threshold. This result, taken together with 2ω interaction measurements at 6x10^{14}w/cm^2, suggest that we should not dismiss the possibility of a 300eV, 2ω ignition target.

This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Prefer an Oral Presentation

34th Annual Anomalous Absorption Conference
Gleneden Beach, Oregon
May 2-7, 2004

Experimental results on small-scale halfraums at the OMEGA laser*

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An experimental campaign to study radiation drive in small-scale halfraums has been carried out using the Omega laser at the Laboratory for Laser Energetics (LLE) in Rochester, NY. Approximately 10 TW of power is incident upon these targets, distributed among three beam cones. These "hot halfraums" fill with plasma so quickly that, late in time, most of the laser energy is deposited outside the laser entrance hole (LEH). The experimental results on radiation drive, laser backscatter, hard x-rays, and x-ray burnthrough are presented as a function of target size and laser smoothing.

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48.

Scattered Light Measurements from Spherical Implosions on OMEGA

W. Seka, C. Stoeckl, R. Jiang, R. E. Bahr, T. C. Sangster, R. S. Craxton, J. A. Delettrez, A. V. Maximov, J. Myatt, and R. W. Short
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To provide experimental input for hydrodynamic simulations of imploding targets, OMEGA has a variety of scattered light diagnostics in routine use. Since the absorption depends on the evolving plasma density and temperature profiles, time-resolved measurements are essential and detailed comparisons with simulations are in progress. Along with other target diagnostics, the absorption measurements provide essential information related to the heat transport models used in the simulations.

Two full-aperture backscatter stations (FABS's) measure the energy and time-resolved spectra scattered through two focusing lenses. Two additional energy measurements and streaked scattered light spectra are obtained between the laser beams. In addition, time-integrated images of the target are taken in between irradiating laser beams.

The scattered light spectra exhibit rapid blue shifts ($\Delta\lambda \leq 0.5$ nm at $\lambda_L = 351$ nm) within the first 200 ps. For solid targets, the wavelength shift subsequently returns to the unshifted laser wavelength; for imploding targets, the signal acquires a redshift toward the end of the laser pulse. These spectral shifts are understood to be Doppler shifts (temporally varying phase shifts) that include motion of the turning point of a particular scattered light ray as well as the temporally changing plasma column traversed by this ray. These shifts are being modeled using input from hydrodynamic simulations, and preliminary results will be presented.

The scattered laser power (integrated over a wavelength range of ± 1 nm) depends strongly on target parameters (imploding versus nonimploding targets) and laser pulse shapes. For 1-ns square pulses the scattered light power relative to the incident power peaks during the first half of the laser pulse, while for shaped pulses with low foot intensities the relative scattered power peaks at the end of the laser pulse. These observations are understood in terms of the evolving plasma density and temperature profiles. Detailed comparisons with hydrodynamic simulations will be presented.

The complex nature of the scattered light paths is reflected in time-integrated images of the target with identifiable contributions from all 60 beams. Detailed simulations show that the angular distribution of scattered light from each beam depends strongly on the target and pulse-shape parameters as well as on the time during the pulse.

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Prefer oral presentation

34th Annual Anomalous Absorption Conference
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Sub-ps Thomson scattering experiment : evidence of large spectral widths and atypical wavenumber spectra of driven IAW and EPW in short pulse interaction

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The understanding of the saturation level of parametric instabilities in large and hot plasmas remains one of the major challenge for the ICF program. Although it has become clear that kinetic physics plays an important role in the saturation mechanisms, it is yet not clear to determine the hierarchy and the quantitative part of the different kinetic events arising in laser-plasma experiments. Thus, sub-picosecond Thomson analysis associated with short pulse interaction could help to explore these topics.

Following the experimental data shown at the preceding Anomalous Conference, we will present new results obtained from experiments also performed in pre-ionized He plasmas ($n_e \sim 5\times10^{19}$ cm^{-3}) using the 100-TW laser facilities (LULI-Ecole Polytechnique). A 3ω, short (300 fs) laser pulse was used as Thomson probe off the electron plasma wave (EPW) and the ion acoustic wave (IAW) respectively driven by stimulated Raman (SRS) and Brillouin (SBS) backscatterings generated in the 1.5 ps, ω laser interaction (pump). The time- and space-resolved Thomson diagnostic has been upgraded to measure the **k**-spectra of the electrostatic waves.

At moderate intensities, $I_{pump} \sim 2\times10^{16}$ Wcm^{-2} i.e. at local intensities currently achieved in the speckle pattern produced by large laser facilities, the extents of the spectral and angular (i.e. in **k**) spectra are larger than the ones predicted by simple linear theory. The Thomson red-shift due to the IAW is typically 10x higher than expected from a cold (300 eV) plasma. The simultaneous measurements of the wavelength and the wavenumber of the EPW show that the EPW's dispersion relation significantly escapes from the standard one. At higher laser intensities, these spectral characteristics are emphasized. In particular, the EPW spectra exhibits a **k**-feature which could be related to the signature of hot electron population produced in the SRS saturation process. These results will be discussed along with strong electron heating.

Oral presentation preferred.

Optical Mixing Generation of KEEN Waves, EPWs and Their Mutual Interactions*

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We will present Vlasov simulation results as well as experimental designs and data on the optical mixing generation of Kinetic Electrostatic Electron Nonlinear (KEEN) waves,[1] electron plasma waves and their interactions in the presence or absence of stimulated Raman scattering (SRS) of the pump wave. For instance, with a blue pump and a green probe beam, we can generate controlled levels of electron plasma waves, amplify the probe beam and instigate probe Raman backscatter instabilities while none were possible in the absence of the primary resonant crossed beam energy transfer process.[2] We can likewise suppress the Raman backscatter of a witness (blue) beam in the presence of these strongly plasma profile modifying activities. This interplay between blue and green interaction beams in a parabolic (exploding foil) density profile gives rise to rich nonlinear phenomena we have had the good fortune to access on the Omega laser system.

The campaign to hunt for recently discovered KEEN waves will begin in June on Trident. This requires an efficient N_2 Raman cell which has recently been completed. With a green pump beam, we will attempt to excite both KEEN waves and EPWs via a Raman downshifted crossing probe beam and in a gas jet plasma. Vlasov simulations motivating these experiments and the physics of KEEN waves will be described in anticipation of these new experimental campaigns. KEEN wave generation and interaction with EPWs, in the presence or absence of the SRS of the pump or probe beam will be discussed. Besides SRS, we will also hunt for the signature of SKS (Stimulated KEEN wave Scattering) and the O(1) levels of phase locked harmonics of the primary ponderomotively driven mode which constitute one of the unique features of KEEN waves.

[1] B. Afeyan et al., Kinetic Electrostatic Electron Nonlinear Waves and their Interactions Driven by the Ponderomotive Force of Crossing Laser Beams, Proc. IFSA, 2003, in press.
[2] B. Afeyan, et al., Optical Mixing Controlled Stimulated Scattering Instabilities, Proc. IFSA, 2003, in press.

*This work was supported by DOE grants DE-FG03-03NA00059/A000 and DE-FG03-03SF22690/A000 and NRL contract N00173-02-C-6019

1960's Plasma Physics Looks at Electron Acoustic Waves (EAW's) and Kinetic Electrostatic Electron Nonlinear Waves (KEEN's),

Wallace Manheimer, RSI Under Contract to NRL Plasma Physics Division, Washington, DC

Recently there have been several published papers[1] speculating on the possible importance of EAW's and KEEN's (these latter as yet, apparently unpublished). These are waves in a pure one dimensional electron plasma which have phase and group velocity roughly equal to the electron thermal velocity v_e. Both experiment[1] and simulation[1] have indicated that these may be important. A plasma physicist coming of age in the 1960's looks upon these with a fair amount of skepticism. He thinks of these waves as strongly Landau damped, $\gamma \sim \omega$, so that scattering from these waves would not be very different from scattering off the electrons. However various theoretical works have provided justification for these, principally pinting out the crucial role of trapped particles. These all relate to the original BGK modes. But in practice, do these waves really exist? and if the do, are they important for laser fusion? This authors tentative answer is that they probably exist, but only in regions of parameter space which are of no concern for laser fusion.

While trapped particles can provide for such a wave even at very low amplitude, one must recall that linear theory shows that it is not the trapped, but resonant particles, i.e. those within γ/k of the phase velocity, which are responsible for the wave damping. For EAW's and KEEN's, these are a very large number of particles and they give rise to very strong damping. Hence it is difficult to escape the conclusion that such a low amplitude wave equilibrium is quite specialized and that any perturbation will allow the modes to damp at their normal rate. There is in fact a linear analog, the van Kampen modes [1], undamped modes at the thermal velocity; yet nearly any superposition of them recovers normal Landau damping. In fact O'Neil has shown that for a single mode, it either damps away if $\gamma > \omega_T$ where ω_T is the trapping frequency, or else assymptotically approaches a BGK mode if $\gamma < \omega_T$. Thus this theory indicates that EAW's and KEEN's should exist only if $\gamma < \omega_T$. This greatly restricts the regions of parameter space where 1960's plasma physics would expect them. Also, this region of parameter space does not overlap the parameter space relevant for laser fusion.

For a turbulent spectrum of waves, the theory is much more complicated, and few have dared tread. One notable exception is Dupree[1] who has proposed theories of clumps and phase space holes. To say that these are difficult would be an understatement, even for a former student of his. Simulations of each have been attempted[1]. The clump simulation saw no EAW's or KEEN's, but the results were consistent with an approach to equilibrium via decaying clumps (i.e. fluctuations were much longer lived than predicted by normal kinetic theory). The simulation was initialized in a phase velocity, wave number and amplitude range where one might expect to see them. The hole simulations also saw no EAW's or KEEN's, but these examined velocities much lower than v_e.

1. Too many references to list here, they will be provided at the talk .

34th Annual Anomalous Absorption Conference
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Can a Langmuir wave's self-focusing beat its decay instability?*

Harvey A. Rose
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A finite, but small amplitude, Langmuir wave, with wavevector **k**, has a trapped particle frequency shift, $\Delta\omega_{\mathrm{TP}} < 0$, that may lead to an associated modulational instability (TPMI). Its threshold and growth rate are calculated explicitly, for the first time, in the short wavelength regime. If the background plasma is in thermal equilibrium, it is shown that TPMI is not possible when $k\lambda_D > 0.46$, while for $0.33 < k\lambda_D < 0.46$, TPMI requires that the fluctuation wavevector have a component perpendicular to **k**, with λ_D the electron Debye length. Its nonlinear evolution may lead to self-focusing. For parameters relevant to recent Trident experiments (Kline et al., submitted to PRL), it is estimated that the Langmuir wave ion acoustic decay instability (LDI) acquires a lower amplitude threshold than TPMI in the range $0.30 < k\lambda_D < 0.35$, consistent with the experimentally observed transition from a kinetic to an LDI regime as the electron temperature decreases. Implications for the saturation of stimulated Raman backscatter are discussed.

*This work was performed under the auspices of the U.S. Department of Energy by the Los Alamos National Laboratory. under Contract No. W-7405-Eng-36.

Modeling of Two-Plasmon-Decay Instability in Direct-Drive ICF Plasmas

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The two-plasmon-decay (TPD) instability is a dominant source of hot electrons in direct-drive inertial confinement fusion (ICF) experiments on the OMEGA laser system.[1] The characteristic feature of direct-drive ICF experiments is that the TPD instability is driven by laser beams randomized in space (due to distributed phase plates) and in time (due to smoothing by spectral dispersion). Another typical feature for the plasmas of OMEGA targets is a large electron-density scale length (on the scale of a few hundred microns) near the quarter-critical density that determines the detuning of the TPD resonance.

A model for the TPD driven by incoherent laser beams has been developed that allows for the calculation of the instability thresholds and growth rates. Analytical predictions have been compared with the results of numerical simulations for single-beam and crossing-beam irradiation. The relation of the new model to the classical three-wave TPD model is discussed.

This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC03-92SF19460, the University of Rochester, and the New York State Energy Research and Development Authority. The support of DOE does not constitute an endorsement by DOE of the views expressed in this article.

1. C. Stoeckl, R. E. Bahr, B. Yaakobi, W. Seka, S. P. Regan, R. S. Craxton, J. A. Delettrez, R. W. Short, J. Myatt, A. V. Maximov, and H. Baldis, Phys. Rev. Lett. 90, 235002 (2003).

Prefer oral presentation

On the Convective Two-Plasmon-Decay Instability in Inhomogeneous Plasmas

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The coupled-mode equations for the two-plasmon-decay (TPD) instability lead to an eighth-order system of differential equations in configuration space. Approximations can be made to simplify this system, but such approximations are invalid for some problems of interest, particularly when the instability occurs near the wave turning points. Consequently, previous researchers[1] have employed Fourier transforms coupled with the assumption of a linear density profile to reduce the TPD problem to a second-order Schrödinger equation in k-space. This formulation was then used to investigate the absolute form of TPD, which manifests itself as a bound-state solution of the Schrödinger equation. In the present work, the k-space formulation is extended to study the convective TPD instability. The k-space equations are integrated from large negative k_x to large positive k_x; the sign of k_x distinguishes incoming from outgoing waves, and the total convective amplification factor is obtained as the ratio of outgoing to incoming plasma wave intensity at large k_x. Thresholds and growth factors obtained from this analysis are compared with results from simplified models, and the transition from convective to absolute instability is discussed.

This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC03-92SF19460, the University of Rochester, and the New York State Energy Research and Development Authority. The support of DOE does not constitute an endorsement by DOE of the views expressed in this article.

1. C. S. Liu and M. N. Rosenbluth, Phys. Fluids **19**, 967 (1976); A. Simon, R. W. Short, E. A. Williams, and T. Dewandre, Phys. Fluids **26**, 3107 (1983).

Prefer oral presentation

Invited Session 4

D. E. Hinkel, Chair

" Plasma Physics at the Anomalous Absorption Conference, as seen by a plasma physicist newly returned to the fold "

- T. W. Johnston

Poster Session 4

Spatially Resolved, Absolutely Calibrated Soft X-ray Spectra at the Nike Laser Facility

J. Weaver[1], U. Feldman[2], G. Holland[3], D. Fielding[4], M. Busquet[2],
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The Nike laser group continues to improve and benchmark the radiation hydrodynamic simulations used to evaluate pellet designs for direct drive inertial confinement fusion. One aspect of this program has been to measure the spectral intensity of emission from irradiated targets using transmission grating spectrometers and filter diode modules which are absolutely calibrated in the soft x-ray regime (hν ~ 0.1-1.0 keV). An extensive database of time-integrated and time-resolved observations has been compiled for a variety of targets (low-Z and high-Z materials), laser conditions, and lines of sight. While comparison of these measurements to detailed non-LTE simulations has demonstrated good agreement (within factor of ~2), possible sources of the remaining discrepancies are still under investigation. Recently, a remotely operable cross-slit has been added near the target to allow one of the transmission grating spectrometers to investigate the 1-D spatial variation in emission across the focal spot at selectable wavelength bands. This poster will present data from the recent campaign with planar targets (CH and Au) and will present a comparison to the non-LTE rad-hydro codes.

Work was supported by DoE

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Measurements of Laser Imprint on Plastic and Cryogenic Foam Targets.

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A quantitative understanding of hydrodynamic instability seeding by laser non-uniformity (laser imprint) is important in predicting performance of direct-drive ICF targets. We are carrying out experiments on imprint on planar plastic as well as cryogenic hydrogen wicked foam targets on the Nike KrF laser with induced spatial incoherence (ISI) smoothing. Most of the imprint occurs during the initial low-intensity part of the pulse, called the "foot" of the pulse, which is necessary to compress the target to achieve high gain. In the experiments, the amount of imprint is controlled by changing the uniformity the foot of the pulse. Measurements of the resulting Raleigh-Taylor amplified areal mass non-uniformity are made by face-on x-ray radiography using Bragg reflection from a curved crystal coupled to an x-ray streak camera. We will present the experimental results and comparisons with 2D simulations using FAST hydrocode.

This work is supported by the U. S. Department of Energy.

Spherical Implosions Using One Sided Illumination

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34th Annual Anomalous Absorption Conference, Gleneden Beach, Oregon, May 2-7, 2004

Abstract

For many years planar targets have been used to experimentally measure the RM-RT growth in targets of similar design to those needed for direct drive inertial confinement fusion. A small section of a pellet is unwrapped onto planar geometry to take advantage of the lower laser energy requirements and ease of diagnostic access. Planar geometry is a reasonable approximation to the behavior of a small section of a spherical pellet as long as the distance traveled is small compared to the pellet radius. Obviously at some point spherical convergence will become an important effect. We would like to take advantage of the diagnostic access provided by one-sided illumination while at least approximately including spherical convergence effects. One possible way of accomplishing this is to use a truncated cone of high-density material to contain the sideways expansion of the target and force it to converge as it accelerates down the cone. Another is to illuminate a hemisphere with some approximation of uniform illumination. We will report on numerical simulations that we have performed to look at some novel target designs that have attempted to provide the desired diagnostic access while simultaneously letting us at least approximately look at the effects of spherical convergence on the RT instability.

Work supported by the U.S.D.O.E. and ONR

prefer poster

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RICHTMYER-MESHKOV INSTABILITY RESHOCK EXPERIMENTS USING LASER-DRIVEN DOUBLE-CYLINDER IMPLOSIONS

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Los Alamos National Laboratory

S. D. Rothman, C. J. Horsfield, and K. W. Parker
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As a shock travels through the interface between substances of different densities, existing perturbations can grow via the Richtmyer-Meshkov (RM) instability. The study of the RM instability in a convergent geometry leads to a better understanding of implosions applicable to inertial confinement fusion and various astrophysical events, such as core-collapse supernovae. We present results of laser-driven double-cylinder implosions performed at the Omega laser facility with an emphasis on sending a second shock through an already shocked RM unstable interface. The uniform reshock of a cylindrical interface is achieved by inserting a second cylinder inside the first that reflects the inwardly travelling shock and causes it to interact a second time with the unstable interface. We present an analysis of the instability growth as a function of shock strength and zero-order perturbation behavior during reshock.

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Calculations of Double Cylinder Implosions at OMEGA

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'AWE, Aldermaston, UK

Foam-filled double cylinder targets have been imploded by the OMEGA laser at the University of Rochester. A marker layer of heavier material is placed between the foam and the outside ablator. The marker layer is hydrodynamically unstable when a strong shock passes through both these interfaces and the marker layer material mixes into the foam and the ablator. These experiments thus measure mix in the compressible, convergent, miscible, strong-shock regime.

With double cylinder targets, the initial shock converges on the central cylinder and then rebounds and expands. The shock is predicted to create even more mixing of the marker layer as it traverses the previously mixed region. The strength of the reflected shock can be varied in the simulations by changing the materials in the inner cylinder. Calculations of these implosions using the AMR code, RAGE, are presented for the several target designs. The 1-D and 2-D calculations give the hydrodynamic evolution of the implosion, shock timings, and the growth of the mix width. The BHR dynamic turbulent mix model is used in these calculations. The calculations also include the effects of surface roughness in the marker layer. Simulated radiographs and mix width calculations of these cylindrical implosions are shown and compared to the experimental results from the recent OMEGA experimental shot series.

This research was performed by the Los Alamos National Laboratory under the auspices of the United States Department of Energy under contract No. W-7405-ENG-36.

(request poster session)

34th Annual Anomalous Absorption Conference
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Modeling the Evolution of Small-Amplitude Perturbations in Converging Spherical Geometry*

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We are concerned with numerically modeling the evolution of small-amplitude perturbations imposed on imploding laser fusion pellets. Our previous work indicated that modern front-capturing methods, such as flux-corrected transport (FCT) methods, total variation diminishing (TVD) methods, and high order Godunov methods (e.g., MUSCL, PPM, ENO, WENO, discontinuous Galerkin methods), were probably not appropriate candidates for such a task because they did not satisfy a "differentiability condition," i.e, the output of these algorithms was not a differentiable function of their input. We also gave examples in planar geometry of numerical algorithms that satisfied the differentiability condition, and which followed the evolution of such perturbations accurately, with extremely high signal-to-noise ratios.

Here we take that work into spherical geometry, where the equations are a bit more complex, and where we are dealing with Legendre modes rather than Fourier modes. Thus far, it appears that the success we had in planar geometry can be replicated in spherical geometry.

* This work was supported by the U.S. Department of Energy

Three-dimensional Rayleigh-Taylor instability in decelerating interface experiments

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D. Arnett, *University of Arizona*

We report experiments performed to study the mixing that occurs at a three-dimensional decelerating interface in a high Reynolds-number flow. The purpose of these experiments is to validate astrophysical codes and to better understand astrophysical phenomena, such as, supernovae. Laboratory systems having large Reynolds numbers ($Re > 10^5$) produce experiments that are well scaled to the conditions in supernovae. These experiments are done at the Omega Laser facility at the University of Rochester.

The targets consist of a beryllium shock tube; within which is polyimide with a brominated plastic tracer strip followed by a lower density C foam. The interface between the two materials has an initial 3D perturbation with a wavelength of 71 μm in two orthogonal directions with an amplitude of 2.5 μm. The surface of the polyimide is irradiated with ~5 kJ of laser energy which creates pressures of ~50 Mbars. These intense pressures cause a high Mach number shock to accelerate the interface into the lower density foam, which decelerates the interface. The resulting mixing of the interface is observed. Financial support for this work included funding from the U.S. Department of Energy to the University of Michigan under grants DE-FG03-99DP00284 and DE-FG03-00SF22021.

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Target hydrodynamics for laser-plasma interaction studies

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Laser-plasma interactions (LPI's) are very sensitive to the hydrodynamic conditions of the plasma. Although the self-consistent coupling of the LPI instabilities with hydrodynamics can be handled numerically (see paper by P. Loiseau *et al.*), these simulations are very time-consuming and are limited to the study of very simple targets such as exploding foils. However, hydro simulations of megajoule-type targets show much more complex hydrodynamics than for exploding foils or the usual gasbags. It is then important to split up long-time plasma evolutions (of the order of 10 ns) into short-time phases (of the order of 1 or 2 ns) which correspond to well-identified hydrodynamic regimes. These regimes could be used as a model to study the self-consistent coupling of the LPI instabilities with hydrodynamics on reasonable time scales.

Two-dimensional numerical simulations of the targets that are planned for LPI experiments on the LIL facility in Bordeaux show a rather complex hydrodynamic behavior of the plasma inside the targets. These targets are cylindrical gas-filled cavities with one or two plastic windows irradiated by a 4+2 ns pulse. In order to identify standard hydrodynamic regimes and also to establish scaling laws for the usual plasma parameters, we analyze in detail old and recent numerical simulations of these targets. Particular attention is paid to the radial and longitudinal evolution of the plasma inside the targets. The representativeness of these plasmas as compared with those of the LMJ targets, from a hydrodynamic point of view, will be discussed and the consequences of these results on LPI will be inferred.

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Development of the Passive Shock Breakout diagnostic for the National Ignition Facility *

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The passive shock breakout (PSBO) diagnostic is an optical imager that projects an image of a target surface onto the slit of a UV-sensitive optical streak camera. It relies on shock luminescence to produce the signal. It can measure shock velocities by detecting the breakout times of a shock propagating through a stepped or a wedge-shaped target sample. This diagnostic will make measurements of shock breakout across witness plates and ablator samples for hohlraum driven targets. Hohlraum drive temperatures will range from approximately 100 eV up to 300 eV or more. These measurements are needed to characterize the hohlraum drive quality and to characterize ablator materials. Accurate characterization of hohlraum drive strength and drive history is an essential need of the inertial confinement fusion program and of the high energy density science program. The current design calls for an F/11.4 Cassegrain telescope, with the primary mirror 42cm in dia. and the secondary mirror placed 1.0m from the primary and 3.5m from the NIF target chamber center (TCC). The telescope image is recorded by an optical streak camera placed outside the target chamber. The Cassegrain telescope is diffraction limited to 7.7 um at TCC; however, the streak camera will limit the actual resolution at TCC to about 10 um at magnification 6.0. The system will be capable of selecting 4 discrete fields-of-view by changing the overall system magnification with the help of additional lenses placed in front of the detector (streak camera). The Cassegrain telescope will have pointing capability, so it can view +/-5 cm at TCC. The system will operate at the main wavelength of 280 nm and it will be protected from the main NIF wavelengths at 351 nm, 527 nm and 1053 nm. The filtering needs to reduce the scattered radiation at those wavelengths by 12-15 orders of magnitude.

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Dirty Secrets: Laser Prepulses and Solid Targets

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While low-intensity laser prepulses are a fact of life in any high intensity laser-plasma interaction, they are an annoying complication to many experimental schemes, particularly in experiments where the laser intensity is varied (presumably these experiments are varying the prepulse intensity as well). To avoid these complications, many lasers are designed such that the peak Amplified Spontaneous Emission (ASE) prepulse intensity is less than some threshold I_{th}. This value is usually taken to be somewhere between 10^{10} and 10^{11} W/cm^2, commonly held to be the ionization threshold of typical solid targets.

We present both previously-published [1] and unpublished experiments which come to the following generally-applicable conclusions:

A) Depending on prepulse duration and precise target material, prepulses can strongly affect laser-solid interactions with ASE intensities as low as 10^8 W/cm^2. At this intensity, the primary mechanism is a melting and boiling of the surface, which then creates a vapor plume. This plume would be unobservable by traditional interferometric techniques, but could still be ionized by the rising edge of the main laser pulse, creating a significant "preformed" plasma.

B) New results show that a uniform vapor plume is not the only mechanism by which a low intensity ASE prepulse interacts with a solid target; scattering measurements show that surface rippling and/or cluster formation is also a large factor on solid Aluminum targets.

C) Any experiment which varies a) laser intensity, b) target material and opacity, or c) target foil thickness can be confounded by a similarly-varying prepulse interaction. Indeed, many previous results attributed to high-intensity laser-plasma interactions can be reinterpreted to simply be a result of low-intensity prepulse effects. [2,3,4]

[1] K.B. Wharton *et al*, Phys. Rev. E **64** 25401 (2001).
[2] R. Benattar *et al.* Opt. Commun. **88**, 376 (1992).
[3] Z. Jiang *et al*, Phys. Plasmas **2**, 1702 (1995).
[4] T. Feurer *et al*, Phys. Rev. E **56**, 4608 (1997).

Poster Session requested

The Weibel instability in fast ignition regimes

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We use analytic theory and PIC simulations to examine how the Weibel instability manifests itself in fast ignition plasma conditions. The resulting physics is a complex interplay of mechanisms related to temperature anisotropy, magnetic pinching and the requirement of current and charge quasineutrality in a plasma.

Both nonrelativistic and relativistic theories are developed for an arbitrary number of particle beams, and distribution functions that describe the properties of each beam. Current neutrality is assumed. We include space charge effects, which in many cases can dominate, even for the early linear stages of modes with wave numbers purely transverse to the direction of the beam propagation.

We have performed a number of PIC simulations to examine the behavior of the instability under very diverse conditions. We have identified the effects predicted by the theory. The conclusions from those runs are applied to explain several large PIC simulations of fast ignitor geometries.

In particular, the fast ignitor simulations do not show violent current filamentation and the subsequent coalescence to a single current jet. Even though current filaments are observed, they develop very slowly and they are always associated with ion density filaments. Additionally they only occur in the vicinity of the laser plasma interface and only few of them merge (locally). To explain these features, we apply our theory to the actual simulation distribution functions of the overdense plasma that is irradiated by an ultraintense laser pulse.

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Thoughts on Return Current Transport through Solid Density, Driven by Ultra-High Intensity Laser/Matter Interaction*

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Ultra-high intensity lasers incident on solid targets generate ~10^8 Amp currents of ~MeV hot electrons. These hot currents must be balanced by equal return currents of ambient electrons. Recent experiments and simple scaling arguments suggest that the fields required to draw those return currents are of order several Volts per atomic spacing: Between ion collisions a return current electron's energy may increase by an amount comparable to kT or $E_{Fermi.}$. The usual notion of conductivity in a plasma whereby the electric field merely *perturbs* the background electron distribution function may be misleading under these circumstances. The high energy tail of the distribution function may become very distorted. We attempt to gain some insight into what may happen to the return current electrons by Monte-Carlo calculations. Instead of representing the solid (e.g. Cu) as a plasma, we treat it as a fixed lattice or gas of Thomas-Fermi atoms, for which the semi-classical differential electron-ion scattering cross section as a function of kT and $E_{electron}$ is explicitly calculated. Results are reported.

* *This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.*

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4P13

Investigation of Fast-Ion Production from Short-Pulse Laser-Matter Interactions*

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In recent years, the production of energetic ions from short-pulse laser-matter interactions has been of great interest. Many theoretical and simulation-based studies have been pursued, in addition to the experiments. In this paper we present a study of how well the particle-in-cell (PIC) method can model the production of highly charged ions. Specifically, we look at the model of Wilks (S. C. Wilks, *et al.*, Phys. Plasmas, **8** 542 (2001).) and see how limitations of the PIC method might affect the results of that model. A number of different physical processes are included in this model: the high intensity laser hitting the target and generating hot electrons ($T_e \sim 1$ MeV); propagation of the electrons through the target (typically a metal foil); and the ionization and acceleration of the ions from the back surface due to a sheath from the hot electrons. The number of particles per cell, grid size and the unphysical noise levels may influence each of these parts, and in different ways. How this may effect predictions will be discussed.

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Poster presentation for the 34th Anomalous Absorption Conference, May 2-7, 2004, Gleneden Beach, OR

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Kinetic modeling of stimulated Raman scattering in laser plasmas

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We use large-scale, well-resolved 1D and 2D Particle-In-Cell simulations to analyze the dynamics of electron plasma waves and stimulated Raman scattering for a variety of laser and plasma parameters, at the picosecond time scale. In low-density, low-temperature plasmas, particle trapping is easily observed and we study its impact on the excited plasma modes. In higher-density, low-temperature targets, plasma wave decay by secondary instability is observed, but some hot electron production still occurs. The situation is contrasted with that of higher-temperature plasmas, typical of ICF. The SRS-driven hot electron current observed in many occasion can magnetize the laser speckles, with significant consequences on the laser – plasma interaction.

Non-equilibrium electron distribution functions and nonlinear thermal transport

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Quasi-self-similar solutions to the stationary electron kinetic equation in diffusive approximation have been found in an inhomogeneous plasma. Electron density and temperature corresponding to these solutions satisfy equation of state, nT^a =const. ($a > 1$). The new electron distribution functions describe particle transport, in particular thermal conduction and ambiporal electric field for the arbitrary amplitude of temperature perturbation in the wide range of particle collisionality. The new solutions display enhanced algebraic tails in the isotropic part and the reduced number of energetic electrons in the anisotropic part of electron distribution functions. The quasi-self-similar theory of electron kinetics is applied to laser plasma heating and heat transport into the overdense region. Calculations of the linear Landau damping rate, growth rate of the return current instability and dynamical form factor are presented.

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A New Plasma Physics Phenomenon: Periodic Kinetic Electrostatic Ion Nonlinear (KEIN) Waves

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This topic, new to basic nonlinear plasma physics, is related to and inspired by recent work on the KEEN waves presented at the 33rd Annual Anomalous Absorption Conference at Lake Placid, at IFSA 2003 [1] and elsewhere dealing with Kinetic Electrostatic Electron Nonlinear (KEEN) waves. Here the single-species positive ion Vlasov behavior (rather than that of the electrons) is followed in detail, while the electrons are represented via a Boltzmann factor (handled in the Vlasov code in a way very close to that described by Cohen et al. [2] for BZOHAR). The new parameter is the electron-to-ion temperature ratio R = Te/Ti (in proper Vlasov terms we mean the ratio for the two species of their thermal energy per particle). When R is very high, the electron shielding is negligible and the results are the same as for the electrons when appropriate re-normalization is applied. When R is very small the electrons do a marvelous job of shielding so little is accomplished. For intermediate results the transition presents features which will be presented to the extent that sufficient results are available. Left for future investigation is the topic of the behavior when two positive-ion species are present (for simplicity assumed to have the same temperature).

[1] B. B. Afeyan, K. Won, V. Savchenko, T. W. Johnston, A. Ghizzo, P. Bertrand Paper # 238, IFSA 2003 (also 33rd AAAC (2003) and ms submitted to *Phys. Rev. Lett.* 2004).

[2] B. I. Cohen et al. *Phys. Plasmas*, **4**, 956 (1997).

Kinetic Simulations of SRS Saturation*

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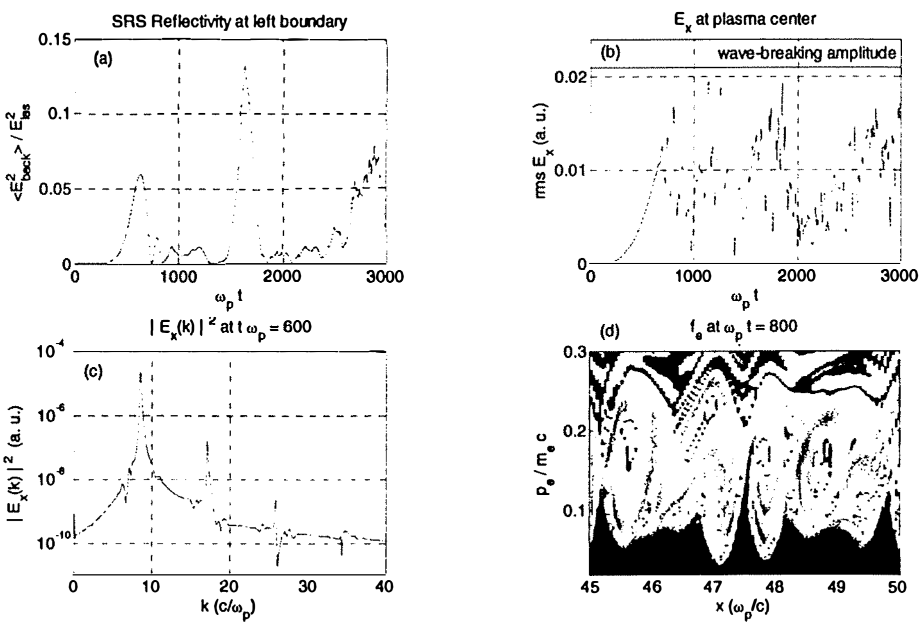
Recent experiments [1] and simulations [2] indicate that kinetic effects are important in SRS saturation. We study this with the 1-D Vlasov-Maxwell code ELVIS, based on the algorithm in [3]. We consider backward Raman scattering of a pump laser driven by a small-amplitude seed laser, chosen to match the frequency of the backscattered wave. We first keep the ions fixed and include no noise. For large enough laser intensities, the daughter EPW can grow to amplitudes comparable to the warm plasma wave-breaking threshold [4]. This entails spatial harmonic generation and strong damping of the EPW as it approaches this amplitude. Upon reaching this threshold, SRS abruptly shuts off, although it recurs in a bursty manner. The phase-space vortices due to electron trapping become severly distorted. Since the EPW does not consist of a single wavelength, effects like the nonlinear frequency shift with wave amplitude [5] may not account for SRS saturation.

We will also run ELVIS with mobile, kinetic ions to explore the ion role (e.g., Langmuir decay instability) in SRS saturation. We are implementing noise in the code to allow other parametric couplings besides the coherently driven SRS to grow.



Numerical results with fixed ions for laser intensity $2{\cdot}10^{15}$ W/cm^2, T_e=500 eV, n_e=$2{\cdot}10^{26}$ m^{-3} , and a homogeneous plasma of length ~$50\lambda_{las}$, showing (a) bursty SRS activity, (b) approach to the wave-breaking limit, (c) spatial harmonics, and (d) phase-space vortex distortion.

[1] D. S. Montgomery, J. A. Cobble, et al., *Phys. Plasmas* **9**, 2311 (2002)
[2] H. X. Vu, D. F. DuBois, B. Bezzerides, *Phys. Rev. Lett.* **86**, 4306 (2001)
[3] A. Ghizzo, P Bertrand, et al., *Journ. Comp. Phys.* **90**, 431 (1990)
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[5] G. J. Morales, T. M. O'Neil. *Phys. Rev. Lett.* **28**, 417 (1972)

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Two-dimensional Kinetic-Ion Simulation of Stimulated Brillouin Backscattering*

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Two-dimensional simulations with the BZOHAR[1] hybrid code (kinetic PIC ions and Boltzmann fluid electrons) are used to investigate the saturation of stimulated Brillouin backscatter (SBBS) instability. The simulation physics model provides a first-principles description of several nonlinearities that can affect SBBS saturation: ion wave breaking and trapping (and the associated nonlinear frequency shift of the ion wave and nonlinear.relaxation of the ion collisionless kinetic dissipation), two-ion-wave-decay instability, harmonic generation, and pump depletion.[1] The simulations address the interplay of these nonlinearities in affecting SBBS saturation as a function of the population of resonant ions controlled by ZT_e/T_i in a single ion species plasma. The effects of sideways transit of the ions across a spatially non-uniform laser beam on the ion trapping and the spatially non-uniform detuning of the SBBS ion wave[2], and the competition of various saturation mechanisms are of particular interest. We also examine the role of ponderomotive filamentation in these simulations. In addition, we shall report on some of the numerical convergence properties of these simulations, which are nontrivial.

[1]B.I. Cohen, B.F. Lasinski, A.B. Langdon, and E.A. Williams, Phys. Plasmas 4, 956 (1997).
[2]L. Divol, RL Berger, BI Cohen, EA Williams, AB Langdon, BF Lasinski, DH Froula, and SH Glenzer, Phys. Plasmas **10**, 1822 (2003).

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(Prefer Poster Presentation)

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Caviton Formation and SBS Saturation in High-Intensity Laser-Plasma Interaction

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Full PIC simulations of stimulated Brillouin backscattering (SBBS) in the high-intensity and low damping regime are presented. The final state of the strongly non-linear evolution of ion-acoustic wave packets consists of caviton formations, which terminate the SBBS build-up and saturate it at a very low level.

The cavity formation is the final state of the ion-acoustic wave (IAW) steepening. The initial process can be well described by a simplified KdV analytical model [J. Candy, W. Rozmus, V. Tikhonchuk, Phys. Rev. Lett. **65**, 1889 (1990)] but it cannot account for wave-breaking and its consequences. As the highly nonlinear IAW gets out of resonance with the ponderomotive force the wave enters a kinetic regime beyond the wave-breaking limit. That kind of X-type wave-breaking has been observed before [D. Forslund, J. Kindel, E. Lindman, Phys. Fluids **18**, 1017 (1975)] in full PIC simulations but their final state has never been considered. The continued steepening of the KdV solution leads to a point where the compressed ion density peak is no longer subject to quasineutrality. The local ion distribution can be approximated by a narrow, δ-function-like structure, while the electrons, due to their much larger thermal velocity, escape the compressed region and spread out. Consequently the ion charge is not balanced and a Coulomb-like explosion takes place inside the bulk plasma (X-type wave-breaking giving an acceleration of ions in both directions). Several peaks inside the wave packet follow consequently the same behavior. The remaining local ion density depressions form a cavity filled in by an electromagnetic field.

The cavitation procedure affects the reflectivity by inducing a transition to a regime of large and non-stationary oscillations and subsequently a saturated purely kinetic regime. Nonlinear effects like harmonic generation and ion trapping are important at an early stage of the interaction process, but neither of them induces a saturation of SBBS. The newly discovered scenario demonstrates the importance of kinetic effects for the nonlinear saturation of Brillouin backscattering.

4P20

34th[d] Annual Anomalous Absorption Conference
Gleneden Beach, Oregon
May 2-7, 2004

NLTE/LTE Equation-of-State Models

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Lawrence Livermore National Laboratory

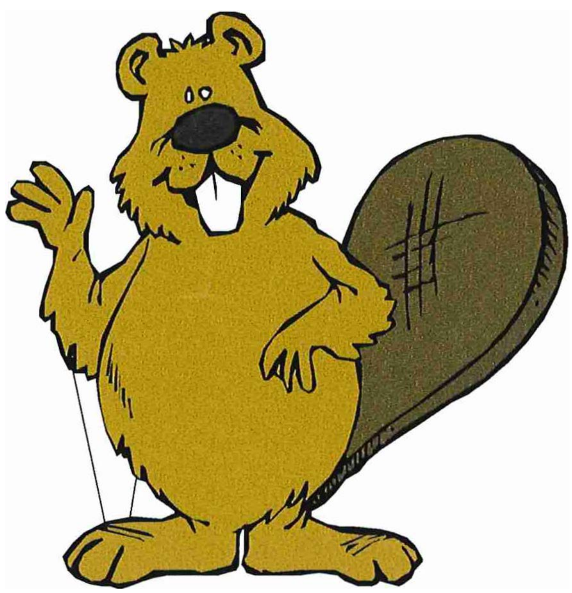
We describe a NLTE EOS model that is obtained by substituting NLTE bound electron populations into a LTE EOS model for dense plasmas. Then the NLTE model naturally possesses the LTE limit, and it also exhibits density effects. Schematically, the NLTE model yields the LTE-like EOS for the free electrons that is consistent with the NLTE bound electron populations and also NLTE density effects according to their LTE form. By this strategy we obtain a NLTE model that couples the EOS and atomic kinetics.

This work was performed under the auspices of the U.S. Department of Energy by University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Friday, May 7, 2004

Daily Program

8:00 AM - 8:45 AM	**Continental Breakfast**
8:45 AM	**Conference Begins**
8:45 AM -10:25 AM	**Oral Session 5**
10:25 AM -10:55 AM	**Break**
10:55 AM - 12:10 PM	**Oral Session 5 Cont**
12:10 PM	**Conference Ends**



Oral Session 5

W. Rozmus, Chair

Radiation Drive with a Composite Laser Pulse Shape*

J. A. Cobble, D. L. Tubbs, N. M. Hoffman, D. C. Swift, T. E. Tierney
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Laser-plasma experiments on the National Ignition Facility will be driven for as long as 20 ns for a variety of campaigns from radiation hydrodynamics and material studies to attempts at thermonuclear ignition. To prepare for those experiments, the present largest national laser facility, the Omega laser at the University of Rochester, is being pressed to and beyond its original design capability. For example, most present Omega experiments are 1 – 3 ns in duration. However to evaluate Rayleigh-Taylor (RT) growth rates in Be, a candidate for NIF ignition-capsule design, it is advantageous to drive the Be samples for longer periods of time so that more RT growth results in a more easily diagnosed material response. To that end, we have designed, deployed, and characterized a 6-ns radiation drive for an Omega hohlraum, which is suitable for such studies. Multiple Omega laser beams have been used to heat a Au hohlraum to create a tailored 6-ns radiation pulse. The cylindrical hohlraum has a single 1.2-mm laser entrance hole. Its diameter and length are 1.6 and 1.2 mm respectively. The laser drive is a composite of two distinct pulse shapes**: a 3.8-ns foot pulse carried by three beams and a 2.5-ns triangular pulse carried by ten beams and delayed to near the end of the foot. Total input energy exceeds 4.25 kJ. The radiation pulse, characterized by soft x-ray spectroscopy (Dante) and velocity interferometry, increases to 80 eV in 0.5 ns, remains constant until 2.5 ns, then ramps up gradually to a peak value of 180 eV at 5.8 ns. The seldom-used lowest Dante channels and VISAR with diamond-turned Be wedges have been especially useful for drive validation. This longer-than-average radiation drive conforms to theoretical needs and is useful for a variety of laser-plasma experiments.

* This work performed under the auspices of the United States Department of Energy.
** The laser pulse shapes were fabricated by Keith Thorp and John Marciante of the University of Rochester.

Drive measurements in scale-3/4 hohlraums on Omega using the proton temporal diagnostic (PTD): Design and analysis *

Peter Amendt, N. Izumi, O.S. Jones, E.L. Dewald, S.H. Glenzer, J.A. Koch, and O.L. Landen
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An experimental campaign to study x-ray drive in scale-3/4 Au cocktail hohlraums using the PTD [1] is underway. Previously, x-ray measurements through the laser-entrance-hole (LEH) with Dante have suggested peak radiation temperatures close to 300 eV for Au hohlraums with a 50% LEH, which is somewhat higher than calculated. By contrast, cocktail hohlraums with a 66% LEH have shown somewhat less drive than expected. A possibility is that emission from outside the LEH is contributing to the Dante signal for the smaller LEH hohlraums. To provide an independent assessment of the changes in hohlraum drive conditions as the LEH and hohlraum wall material are independently varied, the introduction of an imploding capsule is proposed as an integrated drive measurement at target center. The caps ule is filled with 66 atm DHe_3 to accommodate proton-based diagnostics which are nearly 1000x more efficient than standard neutron-based methods. Simulations suggest that shock convergence at the origin or so-called "shoc k-flash" stagnation component of proton production. By contrast, the neutron temporal behavior shows much less discrimination between the two episodes, due to the weaker dependence on ion temperature of the [D+D->He/0.82 MeV)+n(2.45 MeV)] reaction cross-section at the predicted peak ion temperature of 10 keV. An diagnostic signal at shock-flash is useful from the standpoint of avoiding the complicating effects of fuel-pusher atomic mix and radiation flux asymmetry since the capsule has not yet converged significantly. Thus, we propose that detection of the <14.7 MeV proton arrival time could serve as a novel and useful time-integrated hohlraum drive diagnostic. Simulations suggest significantly different proton arrival times for Au vs cocktail and 50% vs 66% hohlraums, well outside of the ±5ps relative timing uncertainty of the PTD. Upcoming experiments in April, 2004 will address the feasibility of this proton-based approach to measuring hohlraum drive at target center.

[1] J.A. Frenje, C.K. Li, F.H. Séguin *et al.*, Phys. Plasmas (to appear); V. Yu Glebov, C. Stoeckl, S. Roberts *et al.*, Rev. Sci. Instrum. (submitted).
* This work was performed under the auspices of U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

Analysis of NIF-scale hohlraum drive symmetry experiments on Omega using point-projection radiography of thin shells*

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Recently a sensitive technique for diagnosing radiation drive asymmetry during the low temperature foot of an indirectly-driven ICF ignition capsule was proposed [1]. In this technique a thin shell of germanium-doped plastic is driven inward by the soft x-ray radiation drive from a laser-heated hohlraum. Before the shell has converged to less than three-quarters of its original diameter, a single high-resolution backlit radiograph of the imploding shell is made with 4.7 keV radiation using a new point-projection backlighting technique [2]. We then infer the low-order (i.e. Legendre modes P1 through P8) asymmetry in the radiation drive from the observed distortions in the position of the limb of the shell. These distortions are measured with an accuracy of 1 micron, which is sufficiently accurate for NIF ignition tuning.

Experiments on the Omega laser were recently done to validate this technique. In these experiments germanium-doped plastic shells of 1.3 mm, 1.6 mm, and 2 mm diameter were driven by a 90-eV hohlraum that approximated the early part of a NIF ignition foot drive. We have simulated these experiments using the HYDRA radiation dynamics code. This has allowed us to model the experiment in three dimensions, which allows us to include non-ideal effects such as beam-to-beam variations in laser power and the azimuthal perturbation caused by the plastic patches on the sides of the hohlraum that are needed in order to make the side-on radiographs. We will compare the calculated shell distortions with the measured distortions in order to quantify the validity and accuracy of this symmetry diagnostic.

[1] S. M. Pollaine, Bull. Of the Am. Phys. Soc., Vol. 45, No. 7, 259 (2000)

[2] D. K. Bradley, O. L. Landen, A. B. Bullock, et al., *Optics Letters*, **Vol. 27**, 134 (2002)

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Rapid Heating of Solid Density Material by the VULCAN Petawatt Laser*

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A solid CH target is heated by the relativistic electrons produced by the VULCAN Petawatt laser focussed to an intensity of more than 1020 Wcm-2. The target is diagnosed by the time resolved X-ray spectrum of a thin buried aluminium tracer layer. The spectrum shows He-like and H-like aluminium lines, K-alpha emission from 'warm' aluminium and a feature which we identify as a 'hollow atom' transition due to a double K shell vacancy.

Analysis of the X-ray line ratios and spectral shapes indicates that material at solid density is heated to more than 500eV to a depth of about 15 mm. and for a duration of more than 10 psec with a corresponding pressure of 0.4 GBar.

The heating data is modeled with the hybrid plasma simulation code LSP from MRC Albuquerque assuming an injected electron distribution appropriate to the experimental laser irradiation conditions. In order to obtain a good fit to the experimental data a laser pre-pulse is invoked which causes resistive inhibition of the laser accelerated electrons in the low density blow off layer and also affects the recirculation of electrons at the front of the target. Other features of the simulation include small scale thermally driven filamentation and gross changes of the electron beam transport if the target density is changed to mimic shock compression.

Interaction of Intense Short Laser Pulse with Cluster Plasma

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Gases of atomic clusters are interesting non-linear media for intense laser matter interaction with applications such as generation of X-rays and extreme ultraviolet radiation, generation of energetic ions and electrons, high harmonic generation and particle acceleration. Recent experiments on laser pulse propagation in gases of clusters have demonstrated effects [1] such as self-focusing of the laser pulse, efficient (>95%) coupling of laser energy to the clusters and broadening of the pulse spectrum.

To understand cluster heating and expansion in intense laser fields, we have performed a series of 2D and 3D electrostatic PIC simulations [2] of the explosion of argon clusters of diameter D_0 in the range 20 nm - 53 nm. Our studies show that at intensities of the order of 10^{16} W/cm^2, heating is dominated by a nonlinear resonant absorption process that gives rise to a size-dependent intensity threshold for strong absorption. There is strong heating when energetic electrons driven through the cluster by the laser field emerge on the other side in phase with the laser field. For $D_0 = 38$ nm, our simulations show a dramatic increase in absorbed energy for peak intensity between 4×10^{15} W/cm^2 and 6×10^{15} W/cm^2.

Propagation of the laser pulse through a gas of clusters is governed by an effective dielectric constant determined by the single cluster polarizability. For computational advantage, we adopt the uniform density description of the exploding clusters, modified to match the single cluster polarizability from experimentally consistent hydro-code runs, and couple it to a Gaussian description of the laser pulse [3]. This model is then used to study self-focusing, absorption, and spectral broadening of the laser pulse.

1. I. Alexeev, T. Antonsen, K. Y. Kim, and H. M. Milchberg, Phys. Rev. Lett. **90**, 103402 (2003); T. Ditmire, R. A. Smith, J. W. G. Tisch, and M. H. R. Hutchinson, Phys. Rev. Lett. **78**, 3121 (1997); K. Y. Kim, H. Milchberg, V. Kumarappan, I. Alexeev, A. Gupta, T. M. Antonsen, Bull. Am. Phys. Soc. **48**, 132 (2003)
2. T. Taguchi, T. M. Antonsen, H. M. Milchberg, submitted to Phys. Rev. Lett.
3. A. Gupta, T. M. Antonsen, H. M. Milchberg, submitted to Phys. Rev. E.

Withdrawn

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Laser-Plasma Interaction experiments on the National Ignition Facility*

S. H. Glenzer, R. L. Berger, G. Bonanno, D. E. Bower, M. Bowers, S. C. Burkhart, K. Campbell, M. P. Chrisp, B. I. Cohen, C. Constantin, E. Dewald, L. Divol, S. Dixit, D. Eder, J. Edwards, D. H. Froula , S. D. Gardner, C. Gates, S. Grace, G. Gregori, R. Griffith, B. A. Hammel, C. Haynam, G. Heestand, M. Henesian, G. Hermes, D. Hinkel, J. Holder, G. Holtmeier, W. Hsing, S. Johnson, O. S. Jones, D. Kalantar, J. H. Kamperschroer, R. Kauffman, T. Kelleher, R. K. Kirkwood, W. L. Kruer, O. L. Landen, A. B. Langdon, S. Langer, D. Latray, A. Lee, F. D. Lee, B. MacGowan, T. McCarville, A. J. Mackinnon, K. Manes, C. Marshall, J. Menapace, N. Meezan, G. Miller, S. Montelongo, J. D. Moody, E. Moses, D. Munro, J. Murray, C. Niemann, A. Nikitin, V. Rekow, V. Roberts, H. Robey, R. Saunders, M. B. Schneider, S. Shiromizu, M. Spaeth, B. Still, L. J. Suter, G. Tietbohl, , M. Tobin, B. M. Van Wonterghem, D. Voloshin, R. Wallace, P. Wegner, P. Whitman, E. A. Williams, B. Young, P. E. Young, J. Fernandez**, D. Montgomery**, H. Rose**

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Abstract

The first experiments on the National Ignition Facility (NIF) have employed the first four beams to measure propagation and laser backscattering losses in large ignition-size plasmas. Gas-filled targets between 2 mm and 7 mm length have been heated from one side by overlapping the focal spots of the four beams from one quad operated at 351 nm (3ω) with a total intensity of $2x10^{15}$W cm^{-2}. The targets were filled with 1 atm of CO_2 producing of up to 7 mm long homogeneously heated plasmas with densities of $n_e = 6 \times 10^{20}cm^{-3}$ and temperatures of $T_e = 2$ keV. The high energy in a NIF quad of beams of 16kJ, illuminating the target from one direction, creates unique conditions for the study of laser plasma interactions at scale lengths not previously accessible.

The propagation through the large-scale plasma was measured with a gated x-ray imager that was filtered for 3.5 keV x rays. These data indicate that the beams interact with the full length of this ignition-scale plasma during the last ~1 ns of the experiment. During that time, the full aperture measurements of the stimulated Brillouin scattering and stimulated Raman scattering show scattering into the four focusing lenses of 3% for the smallest length (~2 mm), increasing to 10-12% for ~7 mm. These results demonstrate the NIF experimental capabilities and further provide a benchmark for three-dimensional modeling of the laser-plasma interactions at ignition-size scale lengths. Upcoming experiments are being planned to measure the scattering outside the lens using a near backscatter imager diagnostics.

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Demonstration of a Polarization Dependent Amplification Produced by Crossing Beams in a Flowing Plasma

R. K. Kirkwood, E. A. Williams, B.I. Cohen, L. Divol, M.R. Dorr, J.A. Hittinger, A. B. Langdon, C. Niemann, J. Moody, L. J. Suter, and O. L. Landen
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Past experiments have demonstrated the saturation of energy transfer between two crossing beams in a plasma with a sonic flow when the pump and probe beam intensities were increased [1]. The amplification of a low intensity probe beam in the presence of a pump was determined by comparison of the fraction transmission of the probe in a experiment where the wave resonance is satisfied (M = +1) to that in a second experiment where the flow direction is reversed and the resonance detuned (M = -1). The amplification is determined as the ratio of these two transmissions and as such is only weakly affected by non-resonant forms of attenuation (such as inverse bremsstrahlung). The saturation as the beam intensities increased has been attributed to the combination of depletion of the pump in localized regions, as well as ion wave non-linearity and was found to be equally effective in both CH and Al exploding foil plasmas where ion wave damping varied over a wide range [2]. When the beam intensity is high and the amplification is reduced well below its unsaturated level, the associated power transfer is difficult to resolve un-ambiguously in the presence of small variations in the non-resonant transmission with time and from shot to shot. Recently we have performed experiments to determine the level of power transfer when the amplification is strongly saturated, both by comparing with a non-resonant experiment at the same high beam intensities, and by simultaneously measuring the transmission of the component of the probe beam that is transverse to the pump. An amplification with a peak value of ~ 1.7x in these experiments for both CH and Al plasmas, even when the probe intensity is ~ 1/3 the pump, further, the amplification does not occur significantly in the cross polarized component of the probe. These results show that adjusting ion wave damping rate will not necessarily suppress energy transfer at resonance, and that controlling the relative polarization vectors of the beams may control energy transfer even when the wave resonance conditions are satisfied.

[1] R. K. Kirkwood et. al. Phys. Rev. Lett. **89**, 215003-1 (2002).
[2] R. K. Kirkwood et. al. In preparation

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(Prefer Oral Session)

Simulations of Laser-Plasma Interaction Experiments on NEL *

Steve Langer, Bert Still, Siegfried Glenzer, Ogden Jones, Ed Williams, and Bruce Langdon
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We have simulated two NEL gasbag experiments using pf3d. The nominal laser intensity was 10^{15} W/cm^2 of 0.35 mm light, but speckles have intensities up to ten times higher than that. The laser beam had a nominal diameter of 0.5 mm and the gasbags had a diameter of 4.5 mm. The first experiment used a neo-pentane gasbag with a length of 5.5 mm, in the laser direction and a density of 8% of critical. The second experiment used a CO2 gasbag with a length of 2.75 mm and a density of 5% of critical. The simulations took roughly 10 days on 1600 processors, so we have only run a few cases.

The experiments did not have transmitted light diagnostics and only measured the back-scattered light that passed through the final focus lens. The neo-pentane experiment found that 11% of the incident light was reflected as SRS and 2% was reflected as SBS. The simulation found that 8% of the laser light was reflected through the lens as SRS and there was negligible SBS. The simulation is close to the experiment. The simulation also ports a number of quantities that were not measured experimentally. 17% of the laser light is transmitted, 60% is absorbed, and 23% is backscattered into all angles as SRS.

The CO2 experiment found that 6% of the incident light was reflected as SBS and 1% was reflected as SRS. The simulation found that 6% of the laser light was reflected through the lens as SBS and there was negligible SRS. The agreement between experiments and simulation is very good. The simulation found that 48% of the laser light is transmitted, 37% is absorbed, and 15% is backscattered into all angles as SBS.

,Side-on volume visualizations clearly show many bursts of SRS that have a fairly short extent in the laser direction (roughly half the length of an f8 speckle). Each burst starts from a small volume of plasma and increases in transverse extent as it propagates back through the plasma. These bursts produce strong variability on sub-ps time scales. The SBS grows independently along each speckle, does not have strong bursts, and varies smoothly in time.

* This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48

Laser coupling in reduced-scale targets*

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Reduced scale targets, i.e., open cans with a 400 μm diameter, have been designed and fielded on the Omega laser at the Laboratory for Laser Energetics (LLE). Approximately 10 TW of power is incident upon these targets, distributed among three beam cones, at 23o, 48o, and 60o. The two innermost cones of beams are conditioned, but the steep angle of incidence of the outermost beam cone precludes beam smoothing. These targets are predicted to have a high electron temperature (15 – 20 keV), and exhibit target filling on the time scale of the pulse length (~ 1 ns). Target filling impacts energy balance by reducing the amount of laser energy that couples to material *inside* the target. This, in turn reduces the radiation drive. Furthermore, significant levels of plasma density *outside* the target cause filamentation and deflection of the laser beam, reducing further the radiation drive. This loss of energy into the can is quantified through pF3D[1] simulations, where a realistic beam propagates through plasma conditions generated by the radiation-hydrodynamic code, Lasnex.[2] In recent campaigns, the radiation flux was determined using Dante as well as x-ray images of burn-through in thin-walled targets. When energy coupling losses, quantified by pF3D simulations, are accounted for in radiation-hydrodynamics simulations, experimental measurements of the radiation drive agree well with predictions by simulations.

1. C. H. Still, R. L. Berger, D. E. Hinkel, L. J. Suter, and E. A. Williams, *Phys. Plasmas* **7**, 2023 (2000).
2. G. Zimmerman and W. L. Kruer, *Comments Plasma Phys. Control. Fusion* **2**, 85 (1975).
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