42nd annual

ANOMALOUS ABSORPTION conference

June 25 –29, 2012
Casa Marina Resort & Beach Club
Key West, FL

Hosted by
Laboratory for Laser Energetics
and University of Rochester

Monday, June 25th, 2012

Room: Big Pine/ Conch, Oral Session, Chair: Dustin Froula (LLE)			
8:30-8:40	Welcome	C. Ren & D. Froula	UR/LLE
8:40-9:00	Kinetic Simulations of Electron Plasma Waves: trapped electron filamentation and sideband instabilities	R. L. Berger	LLNL
9:00-9:20	PIC Simulations of Stimulated Raman Scattering for NIF Scale Lengths and Density Profiles	B. J. Winjum	UCLA
9:20-9:40	Post-Shot Modeling and Analyses of NIF Cryogenic Implosions	D. E. Hinkel	LLNL
9:40-10:00	pF3D simulations of NIF Ignition experiments	E. A. Williams	LLNL
10:00-10:20	Laser propagation and interaction in mm-long and multi-keV plasmas on LIL	P. Loiseau	CEA

10:20-10:50 Coffee Break

Room: Big Pine/ Conch, Oral Session, Chair: Andrew Schmitt (NRL)			
10:50-11:10	Analyses of Long-Scale-Length Plasma Experiments with Different Ablator Materials on the OMEGA EP Laser System	S. X. Hu	UR/LLE
11:10-11:30	Experimental Demonstration of the Two-Plasmon-Decay Common-Wave Process	D. T. Michel	UR/LLE
11:30-11:50	The Effects of Beam Polarization on Convective and Absolute Two-Plasmon Decay Driven by Multiple Laser Beams	R. W. Short	UR/LLE
11:50-12:10	Imaging of Scattered Light Near the Half-Integer Harmonics in OMEGA Implosion Experiments	W. Seka	UR/LLE

Room: Big Pine/ Conch, Invited talk, Chair: William L. Kruer (UC Davis)			
7:00-8:00 pm	Laser-plasma interaction experiments on the National Ignition Facility	J. Moody	LLNL

Monday, June 25th, 2012

Room: Duck/Fiesta/Plantation, Poster Session, 8:00-10:00 PM			
1	PIC simulations of the trapped electron filamentation instability in finite-width electron plasma waves	B. J. Winjum	UCLA
2	LPI Experiments with Single and Multiple NIF beams	D. J. Strozzi	LLNL
3	Influence of Laser Bandwidth on Laser Plasma Instabilities Driven by the Nike KrF Laser	J. L. Weaver	NRL
4	Vlasov Simulations of the filamentation and trapped electron sideband instability	J. W. Banks	LLNL
5	Nonlinear ion acoustic waves in multi-ion species plasmas at low electron to ion temperature ratios	T. Chapman	LLNL
6	Towards an improved characterization of laser plasma coupling in NIF-scale plasmas	W. Kruer	LLNL
7	Implementations of raytrace in the FAST code	A. J. Schmitt	NRL
8	Linear plasma response, electrostatic fluctuations and Thomson scattering	W. Rozmus	LLNL/ U of Alberta
9	Topics in modeling SRS and its hot electrons as they occur within ignition scale hohlraums	M. D. Rosen	LLNL

Tuesday, June 26th, 2012

Room: Big Pine/ Conch, Oral Session, Chair: Peter Amendt (LLNL)			
8:30-8:50	Modeling and observation of after-bang radiative shocks on NIF	L. Divol	LLNL
8:50-9:10	The Phase of Hydrodynamic Growth in Inertial Confinement Fusion Capsules	J. L. Peterson	LLNL
9:10-9:30	Magnetic field generation and growth in Rayleigh-Taylor unstable ICF plasmas	B. Srinivasan	LANL
9:30-9:50	High-Density Carbon (Diamond) Ablator for NIC ignition Capsules	D. Ho	LLNL
9:50-10:10	Silicon-Class Ablators for NIC Ignition Capsules	D. Ho	LLNL

10:10-10:40 Coffee Break

Room: Big Pine/ Conch, Oral Session, Chair: Chuang Ren (UR)			
10:40-11:00	Energetic Electron Generation in the Two-Plasmon-Decay Instability in Direct-Drive Inertial Confinement Fusion	R. Yan	UR/LLE
11:00-11:20	The mitigating effect of electron-ion collisions on hot-electron generation caused by the two-plasmon decay instability in inhomogeneous plasmas	J. F. Myatt	UR/LLE
11:20-11:40	Particle-in-cell Simulations of laser plasma interactions near the quarter critical surface	F. S. Tsung	UCLA
11:40-12:00	Hot Electron Generation by "Cavitating" Langmuir Turbulence in the Nonlinear Stage of the Two Plasmon Decay Instability	H. X. Vu	UCSD

Room: Big Pine/ Conch, Invited talk, Chair: Dustin Froula (UR)			
7:00-8:00 pm	Escape Trajectories from Traditional Condensed Matter	G. Seidler	U Washington

Tuesday, June 26th, 2012

Room: Duck/Fiesta/Plantation, Poster Session, 8:00-10:00 PM			
1	Collisional effects on hot electron generation in the two-plasmon decay instability in inertial confinement fusion	J. Li	UR/LLE
2	ALADIN: A kinetic electron model for validating electron transport	D. Deck	CEA
3	Ion Fokker-Planck simulation of D-3He gas target implosions	O.Larroche	CEA
4	High Energy Density Plasma Created and Investigated by an X-ray Free Electron Laser	B. - I. Cho	LBNL
5	Reverse radiative shock experiments on the omega-60 laser	C. M. Krauland	U Michigan
6	Plasma jets produced by low energy laser interaction with planar and crater targets	E. Louzon	SRC
7	Two-plasmon-decay turbulence driven by the shared-wave triad of two crossed beams	D. A. Russell	Lodestar
8	Study of Laser Plasma Interactions at Intensities of Interest to Shock Ignition Targets Using OSIRIS	F. S. Tsung	UCLA
9	Thomson-Scattering Measurements of Ion-Acoustic Wave Amplitudes Driven by the Two-Plasmon Decay Instability	R. K. Follett	UR/LLE
10	PIC Simulations of the Interaction of Stimulated Raman Scattering in Neighboring Laser Speckles	B. J. Winjum	UCLA

Wednesday, June 27th, 2012

Room: Big Pine/ Conch, Oral Session, Chair: Laurent Divol (LLNL)			
8:30-8:50	Saturation of multi-beams laser plasma interactions by turbulent ion heating	P. Michel	LLNL
8:50-9:10	Mitigation of Cross-Beam Energy Transfer in Direct-Drive Plasmas	D. H. Froula	UR/LLE
9:10-9:30	Mitigation of Cross-Beam Energy Transfer in Polar-Drive Implosions	D. H. Edgell	UR/LLE
9:30-9:50	The Resurgence of Stimulated Brillouin Scattering from NIF hohlraums	R. L. Berger	LLNL
9:50-10:10	Self-organized bursts of coherent stimulated Raman scattering and hot electron transport in speckled laser plasma media	L. Yin	LANL

10:10-10:40 Coffee Break

Room: Big Pine/ Conch, Oral Session, Chair: Lin Yin (LANL)			
10:40-11:00	Studying counterstreaming high velocity plasma flows relevant to astrophysical collisionless shocks	J. S. Ross	LLNL
11:00-11:20	Theory and Validation of Electron-Ion Thermal Relaxation in Fusion and Astrophysical Plasmas	G. Dimonte	LANL
11:20-11:40	Particle acceleration by an intense laser pulse with complex target	Z. M. Zhang	Zhejiang U
11:40-12:00	Anomalous laser absorption by synchrotron radiation and pair production in the ultra-relativistic regime	C. S. Brady	U Warwick

12:00-12:30 **Business Meeting**

6:00-8:30 **Banquet (Flagler Beach)**

Room: Big Pine/ Conch, After-banquet talk, Chair: Chuang Ren (UR)			
8:30-9:30 pm	Some strange things about classical music	J. Dunsby	UR/ESM

Thursday, June 28th, 2012

Room: Big Pine/ Conch, Oral Session, Chair: Frank S. Tsung (UCLA)			
8:30-8:50	Simulations of cone-in-shell targets for integrated fast-ignition experiments on OMEGA	A. A. Solodov	UR/LLE
8:50-9:10	Magnetic Guiding for Electron Fast Ignition	D. J. Strozzi	LLNL
9:10-9:30	Time-resolved study of hole boring at relativistic intensities in front of solid targets	Y. Ping	LLNL
9:30-9:50	Channeling of relativistic laser pulses in underdense plasmas and subsequent electron acceleration	N. Naseri	U Alberta
9:50-10:10	Laser hosing in relativistically hot plasmas	C. Ren	UR/LLE

10:10-10:40 Coffee Break

Room: Big Pine/ Conch, Oral Session, Chair: John Moody (LLNL)			
10:40-11:00	On the potential role of species separation and anomalous energy dissipation in DT thermonuclear fuels	P. Amendt	LLNL
11:00-11:20	Effects of ion diffusion on fusion burn at the shock flash in inertial-confinement fusion implosions	C. K. Li	MIT
11:20-11:40	Dependence of the fusion yield on the separation of d and t ions in exploding pusher simulations	C. Bellei	LLNL
11:40-12:00	Ion concentration diffusion in ICF implosions	G. Kagan	LANL

Room: Big Pine/ Conch, Invited talk, Chair: Richard Berger (LLNL)			
7:00-8:00 pm	Advanced ablator target designs for shock and hot spot ignition on the National Ignition Facility	R. Betti	UR/LLE

Thursday, June 28th, 2012

Room: Duck/Fiesta/Plantation, Poster Session, 8:00-10:00 PM			
1	Relativistic Particle Wakes and Their Impact on Electron Stopping	I. N. Ellis	UCLA
2	Acceleration and Transport of Electrons Created Using High Intensity Lasers and High Density Targets	J. May	UCLA
3	Acceleration of relativistic electrons in plasma channels	N. Naseri	U Alberta
4	Hot Electron Generation from laser-pre-plasma interactions in cone guided Fast Ignition	J. Li	UR/LLE
5	Collisional PIC modeling of plasma instabilities	L. Divol	LLNL
6	Hybrid-PIC simulations of shock formation in laser-irradiated plasmas	A. Tableman	UCLA
7	Implicit Vlasov-Fokker-Planck simulations for non-uniformly laser-irradiated plasmas	M. Tzoufras	UCLA
8	2D hydrodynamic simulations for the interpretation of the controlling fast electron beam divergence using two laser pulses experiment	G. Malka	U Bordeaux
9	Magneto-Hydrodynamic Effects in Ablatively-Driven High Energy Density Systems	L. Gao	UR/LLE

Friday, June 29th, 2012

Room: Big Pine/ Conch, Oral Session, Chair: Riccardo Betti (UR)			
8:30-8:50	Extremely high pressure generation by implosion plasmas with cone-in-shell targets	K. Shigemori	Osaka U/ILE
8:50-9:10	Study on energy loss of energetic electrons in dense plasmas	S. Z. Wu	IAPCM
9:10-9:30	Getting Results From K α Images and Yields Using LSP	D. Schumacher	OSU
9:30-9:50	Mean Fast Electron Energy in Laser-Solid Interactions from 1E18 to 1E19 W cm-2 Determined from Time Resolved K alpha Emission	J. R. Davies	UR/LLE
9:50-10:10	Interaction of Multiple Laser Beams via Common Ion Waves and Beam Energy Transfer	A. V. Maximov	UR/LLE

10:10-10:40 Coffee Break

Room: Big Pine/ Conch, Oral Session, Chair: Jonathan Davies (UR)			
10:40-11:00	Hybrid-PIC simulations of shock formation in laser-irradiated plasmas	A. Tableman	UCLA
11:00-11:20	Particle-in-cell simulations on high-intensity femtosecond laser pulse sub-wavelength structured target interactions	W. - M. Zhou	CAEP
11:20-11:40	High charge fast electron acceleration by laser self-focusing effect	Z.- Q. Zhao	CAEP

Monday, June 25th 2012

Kinetic Simulations of Electron Plasma Waves: trapped electron filamentation and sideband instabilities

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E. J. Valeo
Princeton Plasma Physics Laboratory, Princeton, NJ 08540
(Dated: April 30, 2012)

Vlasov and PIC simulations of nonlinear electron plasma waves (EPW) are presented in 2D with the Vlasov code LOKI (2 space and 2 velocity dimensions; Banks et al., Phys. Plasmas 18, 052102 (2011)) and the electrostatic PIC code BEPS (V. K. Decyk, Computer Phys. Comm. 177, 95 (2007)). EPWs are created with an external traveling wave potential with uniform amplitude transversely or with a transverse envelope of width Δy. In the latter case, the transverse envelope mimics waves created in a laser speckle, with thermal electrons transiting the wave in a "sideloss" time, $t_{sl} \sim \Delta y/v_e$, where v_e is the electron thermal velocity. The evolution of the plasma wave field and associated self-consistent quasi-steady distribution of trapped electrons is studied after the external drive is turned off. For finite-amplitude EPWs, the onset of the trapped-electron-induced filamentation instability (H. Rose, Phys. Plasmas 15, 042311 (2008)) and trapped electron sideband instability (S. Brunner and E. Valeo, PRL 93, 145003 (2004)) are studied as a function of wave amplitude and $k_0\lambda_{De}$, where k_0 is the wavenumber of the external potential. Both instabilities are found to exist for larger $k_0\lambda_{De}$ and wave amplitudes than predicted.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 and funded by the Laboratory Research and Development Program at LLNL under project tracking code 12-ERD-061.

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PIC Simulations of Stimulated Raman Scattering for NIF Scale Lengths and Density Profiles*

B. J. Winjum, F. S. Tsung, and W. B. Mori
University of California, Los Angeles

Stimulated Raman scattering (SRS) is deleterious for laser-driven inertial confinement fusion because incident laser energy can be reflected backwards, absorbed where it was not intended to be, and absorbed into energetic electrons that can preheat the fuel. Particle-in-cell (PIC) simulations (using OSIRIS and other codes) for plasma conditions close to those at the National Ignition Facility (NIF) have shown SRS to be bursty in space and time, with localized plasma wave packets for sub-speckle-length scales and bursts of light on the sub-picosecond time scale. However, these simulations have predominantly simulated speckle-size plasmas. Here we present one- and two-dimensional PIC simulation results for plasmas 0.7-1.5 mm in length, T_e = 2.5-3.0 keV, laser intensities 4-8 x 10^{14} W/cm^2, and with NIF-relevant density profiles covering n_e/n_{cr} = 0.09-0.15.

Most SRS bursts are again spatially localized within 200 microns and generate sub-picosecond bursts of light whose periodicity is related to the nonlinear plasma wave frequency shift as shown in our previous work. For linearly increasing density profiles with scale lengths ~3 mm, SRS is shown to initially grow at densities of n_e/n_{cr} ~ 0.13-0.14, corresponding to $k\lambda_D$ < ~0.30. For other density profiles with changing slopes or regions of uniform density, SRS is shown to grow at densities below n_e/n_{cr} = 0.11 provided the slope in density is sufficiently shallow. The location of SRS growth changes very little as laser intensity increases, although additional bursts start occurring at lower densities. Rescatter is also observed under some conditions. We discuss the range of scattered light wavelengths, the reflectivity levels, and the hot electron spectra.

*Supported under Grants DE-FG52-09NA29552 and NSF-Phy-0904039; simulations were performed on the UCLA Hoffman2 Cluster and NERSC's Hopper II.

Post-Shot Modeling and Analyses of NIF Cryogenic Implosions

D. E. Hinkel, D. S. Clark, D. C. Eder, and O. S. Jones
Lawrence Livermore National Laboratory

Cryogenic fuel layer experiments are currently underway at the National Ignition Facility (NIF). These experiments compress a ~ 1mm sphere comprised of DT gas, frozen DT, and an ablator into a high density, cold shell that surrounds a low density hotspot where fusion is initiated. Accompanying experiments provide shock timing[1] and converging ablator[2] information about these implosions.

Post-shot modeling uses a tuned radiation source that is currently a best effort to match shock timing data, converging ablator data, bang time, and the fuel areal density. Tuned radiation sources are then utilized in multi-dimensional capsule simulations with representations of the as-shot ablator surface roughness and ice roughness, a representation of the largest groove present in the DT ice layer, the capsule tent, and radiation asymmetry derived from integrated hohlraum-capsule simulations. They are also used in growth factor simulations.

Presented here is an example of how a radiation source is tuned, and the subsequent results from a 2D simulation. A comparison of the suite of simulations to the experimental results is included.

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

[1] T. R. Boehly *et al*., Phys. Plasmas **18**, 092706 (2011).
[2] D. G. Hicks *et al.*, Phys. Plasmas **17**, 102703 (2010).

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pF3D simulations of NIF Ignition experiments

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

Lawrence Livermore National Laboratory, Livermore CA 94550

We have been using our laser plasma interaction code pF3d to gain insight into stimulated scattering (SRS and SBS) in NIF ignition hohlraums. pF3d had success in modeling Omega experiments in which a single probe beam was propagated along a hohlraum axis, predicting the backscatter reduction from beam smoothing. Satisfactory reflectivities were obtained, saturating via local pump depletion, without the invocation of any reduced models for the nonlinear evolution of the plasma and ion acoustic waves[(1)].

Simulating a NIF ignition hohlraum is more challenging. In the Omega experiments we had some Thomson scattering data to validate the plasma conditions; in NIF we use the SRS and SBS spectra to sanity check the plasma modeling, but direct measurements are lacking. Early inconsistency in the observed and anticipated spectra pointed to improved modeling[(2)]. In addition, the scale of the Omega experiments allowed for modeling the entire probe beam path with a modest number (1000's) of CPUs. Modeling the entire volume traversed by neighboring NIF beams is not feasible on current machines, necessitating restricting the simulation to the anticipated interaction volume.

The larger scale and the beam geometry of NIF make multi-beam effects of greater importance. Wavelength tuning gives rise to large, non-uniform energy transfer between the outer and inner beam cones. Multiple beams overlap in the region of SRS inner beam generation. We use a variety of tools, including SLIP, to prepare suitable inputs and post-process the outputs of large-scale pF3d simulations designed to assess these effects. Their inclusion increases the simulated reflection, bettering agreement with experimental observation.

This work was performed under the auspices of the U.S. DOE by Lawrence Livermore National Laboratory under contract DE--AC52--07NA27344.

*(1) Divol et. al. PRL **100**,25001 (2008) (2) Rosen et. al. High Energy Density Physics **7**, 180 (2011)*

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Laser propagation and interaction in mm-long and multi-keV plasmas *on LIL*

P. Loiseau, C. Rousseaux, G. Huser, M. Casanova, D. Teychenné, P.-E. Masson-Laborde and M.-C. Monteil

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In order to achieve ignition in the indirect drive scheme, high power lasers have to propagate in a cm-long and multi-keV hot plasma. All along their path, the lasers undergo many phenomena such as absorption, stimulated scattering on plasma waves leading to Raman (SRS) or Brillouin (SBS) scattering, or self-focusing. In an ignition hohlraum, lasers are assembled by cones. The outer cones correspond to an irradiation near the laser entrance hole with high irradiation angles and shorter laser path, while the inner cones have lower irradiation angle and longer laser path. Linear gains calculations indicate [1] that the inner cones are mainly sensitive to SRS, while outer cones are sensitive to SBS. We use the LIL facility, a well-diagnosed facility and a prototype of one LMJ quad, in order to mimic such behaviours.

We have designed targets where the laser beam propagates into a mm-long under-critical pentane plasma, that fills a gold cylinder, and targets where the laser interacts with a plasma first composed of pentane, then of gold coming from the wall expansion [2]. We focus on the first target representative of an inner beam plasma conditions. The campaign was conducted in 2011. We shot 4 mm and 1.5 mm long targets with various beam conditioning. The laser pulse is 6 ns long with a maximum energy of 15 kJ. As expected, we measured mainly SRS signals, giving a bacskscattered energy fraction of 20% of the incident laser energy. We will present experimental results of the backscattering and transmission stations, together with radiative-hydrodynamics and paraxial simulations.

[1] S. Laffite et P. Loiseau, Phys. Plasmas 17, 102704 (2010)
[2] P. Loiseau *et al.*, Bull. Am. Phys. Soc. 56, vol.12, 60 (2011)

Prefer **oral** session

Analyses of Long-Scale-Length Plasma Experiments with Different Ablator Materials on the OMEGA EP Laser System

S. X. Hu*, D. H. Edgell, D. H. Froula, V. N. Goncharov, D. T. Michel, S. Skupsky, and B. Yaakobi

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This work reports on analyses of long-scale-length plasma experiments with a variety of ablator materials (including plastic CH, saran, and aluminum) performed on the OMEGA EP Laser System using the two-dimensional radiation–hydrodynamics code *DRACO*. It is essential to understand laser–plasma instabilities (LPI) in long-scale-length plasmas for direct-drive ignition at the National Ignition Facility (NIF). For example, direct-drive–ignition targets on the NIF with plastic CH ablators have a density scale length of L_n ~ 500 μm at the quarter-critical region. For a drive laser intensity of ~8 × 10^{14} W/cm^2, the two-plasmon-decay (TPD) instability may grow above its gain threshold in such long-scale-length plasmas. Mitigating the TPD instability in NIF-scale plasmas is important for direct-drive ignition, as hot electrons generated from the TPD instability may compromise the fuel compression. One of the TPD mitigation strategies is to search for the appropriate ablator materials that can not only suppress the TPD instability, but also guarantee acceptable hydro-drive efficiency. For these purposes, we have performed planar-target experiments using different ablator materials and large distributed phase plates on the OMEGA EP Laser System. We have found that for the same laser intensity on target, the TPD-induced hot electrons were significantly reduced by a factor 3 to 10 when saran and aluminum ablators are used, in comparison with plastic CH. Moreover, the drive pressure for the saran ablator was found to be very similar to plastic CH. We hope that such experiments and analyses will assist us in finding the optimal ablator material for both TPD mitigation and efficient drive.

This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC52-08NA28302, 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

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Experimental Demonstration of the Two-Plasmon-Decay Common-Wave Process

D. T. Michel, A. V. Maximov, B. Yaakobi, S. X. Hu, J. F. Myatt, A. A. Solodov, R. W. Short, and D. H. Froula

Laboratory for Laser Energetics, University of Rochester
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An experimental demonstration of multiple laser beams sharing a common plasma wave in the two-plasmon-decay (TPD) instability is presented. When maintaining a constant overlapped intensity, the total energy in hot electrons is measured to be the same for one- or two-beam experiments and significantly smaller when four beams are used.[1] A theory for the common-wave process explains the experimental results. The theory predicts that two laser beams can drive only a common TPD electron-plasma wave in the plane bisecting the two beams and that for more than two beams, this process is limited to a line or cannot occur. A common wave gain is shown to be proportional to a geometrical factor (ranging between 0.5 and 1 for practical cases) times the overlapped intensity. This theory explains that because only beams of a given cone interact, experiments where 18 beams in three cones are used results in a significant decrease of the TPD for similar overlapped intensities. The theory predicts that TPD growth is proportional to the overlapped laser beam intensity when beams are symmetric and polarization smoothing [distributed polarization rotator (DPR)] is used as observed in previous experiments.[2]

This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC52-08NA28302, 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. D. T. Michel *et al.*, “Experimental Demonstration of the Two-Plasmon-Decay Common-Wave Process” submitted to Physical Review Letters.
2. C. Stoeckl *et al.*, Phys. Rev. Lett. **90**, 235002 (2003)

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The Effects of Beam Polarization on Convective and Absolute Two-Plasmon Decay Driven by Multiple Laser Beams

R. W. Short, J. F. Myatt, A. V. Maximov, D. T. Michel, and D. H. Froula

Laboratory for Laser Energetics, University of Rochester
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There is now much evidence that two-plasmon decay in direct-drive geometries is a collective process, in which a given set of decay waves is driven by two or more laser beams.[1,2] Since the single-beam decay is maximized on a hyperbola lying in the plane of polarization of the beam, maximum gain for the multibeam process is constrained to the vicinity of the intersection of the hyperbolas corresponding to the beams involved. As a result, the nature of the decay depends on the relative orientations and polarizations of the beams. It is found that when the polarizations of two beams lie in the plane of their wave vectors, they drive a collective mode with a large plasmon wave vector **k**; while when they are polarized out of this plane, the collective mode is at small **k**. In the latter case the instability can be absolute. For more general polarizations, or when polarization smoothing is used, both types of decay may be present. The consequences of these results for multibeam laser–plasma experiments will be discussed.

This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC52-08NA28302, 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 *et al.*, Phys. Rev. Lett. **90**, 235002 (2003).

2. D. T. Michel *et al.*, “Experimental Demonstration of the Two-Plasmon-Decay Common-Wave Process,” submitted to Physical Review Letters.

Prefer oral presentation.

Imaging of Scattered Light Near the Half-Integer Harmonics in OMEGA Implosion Experiments

W. Seka, D. H. Froula, T. D. Michel, J. Katz, R. E. Bahr, J. F. Myatt, R. W. Short, A. V. Maximov, and V. N. Goncharov

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Imaging the half-integer harmonic emission ($3\omega/2$ and $\omega/2$) from imploding targets yields information regarding the two-plasmon-decay (TPD) instability occurring between $0.25 \le n_c/n_e \le 0.2$ (typical Landau cutoff location). The $3\omega/2$ light is generated via Thomson scattering of one of the irradiating beams and a TPD plasmon generated by other beams. This light can be principally emitted in almost any direction, although the laser irradiation geometry imprints itself on these images in a complex way. In contrast, the $\omega/2$ light can be generated by various processes but is emitted only close to the density gradient (in the radial direction). The smaller the k_{perp} of the plasmons involved, the more this emission is limited to the radial direction. We present half-integer harmonic images of imploding targets irradiated with two different beam sizes (tangential illumination and illumination by beams of roughly half that size). These images along with irradiation patterns on target allow for inferences to be made regarding where on the target the TPD instability is likely to be driven. In particular, this allows for inferences regarding TPD driven by multiple beams and whether TPD is significantly driven very close to $n_c/4$, i.e. TPD plasmons with small k_{perp}.

This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC52-08NA28302, 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.

Laser-plasma interaction experiments on the National Ignition Facility

J. D. Moody, D. J. Strozzi, P. Michel, L. Divol, R. L. Berger, E. Bond, D. K. Bradley, D. Callahan, S. Dixit, S. Glenn, S. H. Glenzer, A. Hamza, D. E. Hinkel, N. Izumi, O. Jones, J. Kilkenny, R. K. Kirkwood, J. L. Kline[1], G. A. Kyrala[1], W. L. Kruer, O. L. Landen, S. LePape, B. J. MacGowan, N. B. Meezan, A. Nikroo[2], R. P. J. Town , K. Widmann, and E. A. Williams
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Backscatter measurements on NIF have provided significant experimental guidance to understanding hohlraum plasma conditions, cross-beam energy transfer, and hohlraum energetics. In addition, the measurements have been important in evaluating the impact of hohlraum size, beam-pointing, focal spot size, laser entrance hole liners, gas fill, pulse shape, etc. on laser-target coupling. In general, ignition hohlraums are dominated by stimulated Raman Scattering (SRS) with a fairly low level of stimulated Brillouin scattering (SBS) on the inner beams and some SBS on the outer beams. Departures from these general trends are interesting as they give insight into the hohlraum plasma and instability behavior. For example, there are cases with significant increases in SBS, evidence of competition between SRS and SBS, changes in the SRS spectra, refraction, and time-history, and more. A series of recent experiments has deliberately set out to distinguish multi-beam from single-beam backscattering in ignition hohlraums by selectively shutting off certain beams and not others. These studies provide a way to estimate the magnitude of cross-beam energy transfer and re-amplification and allow essentially single-quad LPI experiments in ignition hohlraums. This talk will review the general trends in the NIF backscatter data and show how departures from these trends can shed light on the hohlraum plasma and interaction physics. In addition, the talk will discuss the recent studies aimed at distinguishing multi-beam from single-beam effects. Finally, several suggestions are made of some possible NIF experiments that could provide further insight into the LPI physics processes active in these hohlraum plasmas.

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PIC simulations of the trapped electron filamentation instability in finite-width electron plasma waves

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We present results on the kinetic filamentation of finite-width, nonlinear electron plasma waves (EPW) through 2D kinetic simulations with the electrostatic PIC code BEPS (V. K. Decyk, Computer Phys. Comm. 177, 95 (2007)). An externally imposed ponderomotive driver excites a traveling wave with a Gaussian profile in the transverse direction and a normalized wavenumber $k_0\lambda_{De} = 1/3$. The evolution of the plasma wave field and associated distribution of trapped electrons is studied after the external drive is turned off. Doubly periodic simulations of systems one wavelength long ($L_x = 2\pi/k_0$) in the propagation direction but hundreds of Debye lengths transversely allow us to exclude wave modulations due to the longitudinal sideband instability and focus on the wave modulation due to transverse filamentation. In particular, we compare our results with the trapped-electron-induced filamentation instability (H. Rose and L. Yin, Phys. Plasmas 15, 042311 (2008)). We find that the transverse wavenumber spectrum broadens during transverse EPW localization for small width (but for sufficiently large amplitude) waves, while the spectrum narrows to a dominant $k_\perp$ as the initial width of the wave is increased to the plane-wave limit. When the EPW width is large, filaments can grow and destroy the wave coherence before transverse localization destroys the wave, with the filaments in turn evolving individually as self-focusing EPWs. The transverse wavenumber growth rates vary smoothly with $k_\perp$ when localization dominates filamentation, but when filamentation dominates, that is, for waves of sufficiently large width, the growth rate of the most unstable filamentary modes is proportional to $\mathrm{e}\phi_0/\mathrm{T_e}$ as found for the plane wave simulations, where ϕ_0 is the maximum wave amplitude. The electron distribution function reflects the filamentary structure of the field as well as additional interesting features related to the detrapping of electrons as they travel through spatially varying trapping regions. In particular, a transverse electric field develops that can accelerate electrons into and out of a trapping region, and a beam-like distribution of untrapped electrons develops between filaments, or equivalently on the sides of a localizing EPW.

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LPI experiments with single and multiple NIF beams

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Experiments on NIF have recently been performed with less than the full set of four cones of laser beams, to elucidate laser-plasma interactions (LPI). In particular, the laser pulse on a subset of cones has been extended at the end of shock-timing, or "keyhole", shots. These entail measuring the shock velocities and timings in a hohlraum-driven capsule with the VISAR detector. The shots usually end in the middle of the peak-power portion of a full-ignition pulse. Extending one or two cones allows LPI to be studied in a NIF hohlraum, but without the full range of multiple-quad interactions, such as cross-beam energy transfer and backscatter re-amplification.

The Raman backscatter power from an inner cone drops substantially (~3-4x) when the other cones are shut off. We discuss the constraints this imposes on cross-beam energy transfer and re-amplification. We report on comparison of LPI modeling tools, namely linear gains and pF3D, to single-quad experiments.

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Influence of Laser Bandwidth on Laser Plasma Instabilities Driven by the Nike KrF Laser*

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In the original studies of beam smoothing by induced spatial incoherence (ISI) at first and second harmonics of a Nd:glass laser system**, stimulated Raman scattering, stimulated Brillouin scattering, and the two plasmon decay instability were reduced when sufficiently wide bandwidth ISI ($\delta\nu/\nu$ ~ 0.03-0.19%) pulses irradiated targets at moderate to high intensities (10^{14}-10^{15} W/cm^2). The Nike krypton-fluoride (KrF) laser at the Naval Research Laboratory operates in the deep UV (248 nm) and also incorporates ISI. LPI studies at Nike have shown that the intensity threshold for quarter critical instabilities increased with the expected wavelength scaling, without taking into account the large bandwidth of the Nike laser ($\delta\nu \sim 1-3$ THz) in its standard configuration. The bandwidth of KrF lasers can be increased or decreased by the addition of etalons in the initial stages of the laser chain. New experiments are underway that will compare the previous results to laser plasma instabilities (LPI) driven by narrower bandwidth pulses. This presentation will discuss the performance of Nike with modified spectral profiles and observations of LPI in planar CH targets. **Obenschain, PRL **62**, 768 (1989); Mostovych, PRL, **59**, 1193 (1987); Peyser, Phys. Fluids B **3**, 1479 (1991)

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Vlasov Simulations of the filamentation and trapped electron sideband instability

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Kinetic simulations of nonlinear electron plasma (EPW) waves in 2D (2 space and 2 velocity dimensions) are investigated using the Vlasov code, LOKI (Banks et al , Phys Plasmas 18, 052102 (2011)). Traveling plane electron plasma waves (BGK type waves) are created using an external wave potential with wavenumber k_0 where $0.27 < k_0\lambda_{De} < 0.42$. The driver frequency is chosen to be the real part of the frequency of the Landau root. Spatially periodic boundary conditions are imposed . The evolution of the plasma wave field and associated self-consistent quasi-steady distribution of trapped electrons is studied after the external drive is turned off. The trapped-electron-induced filamentation (H. Rose, Phys. Plasmas 15, 042311 (2008)) instability is studied using systems which are one wavelength long axially ($L_x = 2\pi/k_0$) (along the propagation direction), but hundreds of Debye lengths transversely. Because of the low noise feature of Vlasov, transverse modes are seeded and their linear growth is followed to nonlinear saturation. The growth rate of the most unstable mode is found to be proportional to $\mathrm{e}\phi_0/\mathrm{T_e}$ where ϕ_0 is the wave amplitude of the "BGK" wave, while the wavenumber of this mode is proportional to $\sqrt{\mathrm{e}\phi_0/\mathrm{T_e}}$. This instability persists even for $k_0\lambda_{De} > 0.35$. The trapped electron sideband instability(S. Brunner and E. Valeo, PRL 93, 145003 (2004)) is studied as a function of the wave amplitude and the $k_0\lambda_{De}$ for plasma lengths $L_x \gg 2\pi/k_0$ in both 1D and 2D simulations. The growth rate is found to be in good agreement with the Kruer et al theory (Kruer et al, PRL 1969). Both the sideband and the filamentation instabilities are found to co-exist for a large range of $k_0\lambda_{De}$ and wave amplitude. These results are confirmed by PIC simulations with the BEPS code.

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Nonlinear ion acoustic waves in multi-ion species plasmas at low electron to ion temperature ratios

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(Dated: April 26, 2012)

In experiments with laser pulses of 1-2 ns duration, the dominant ion acoustic wave (IAW) mode in multi-ion species plasmas is the so-called fast mode with phase velocity larger than the thermal velocities of all ion species. However, if the ion temperature approaches the electron temperature, as predicted by hydrodynamic simulations for current NIF hohlraum experiments, the slow IAW mode, with phase velocity intermediate between the light and heavy ion thermal velocities, can become less damped than the fast mode and thus be more easily driven. Using a spatially one-dimensional Vlasov code, the impact of nonlinear effects, such as harmonic generation and both electron and ion trapping, on the evolution of IAWs in multi-ion species plasmas is studied in detail over a range of electron to ion temperature and light to heavy ion species ratios.

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Towards an improved characterization of laser plasma coupling in NIF-scale plasmas

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To date laser plasma coupling has been "good enough" (i.e., gives sufficient drive as well as sufficiently controllable symmetry) to enable numerous well-diagnosed NIF implosion experiments. On a longer time scale, an improved characterization of laser plasma coupling in NIF-scale plasmas is desirable both for ignition and other high energy density physics experiments. Important issues include the time-dependence of the cross beam energy transfer, the role of stimulated sideward scattering of laser light in the hohlraum, overlapping beam effects on stimulated scattering, the efficiency with which quarter-critical density instabilities generate superhot electrons, and the evolving plasma conditions within the hohlraum. Simple experiments to address some of these issues are discussed.

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Implementations of raytrace in the FAST code*

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Abstract

An accurate description of laser light in the underdense plasma coronas of inertial fusion targets is needed in order to properly calculate both the magnitude and the uniformity of the laser deposition, which determines the drive pressure. The customary way of doing so involves solving the equations of geometrical optics[1] for individual rays in each laser beam and depositing the ray energy as it is absorbed into the plasma[2]. A fundamental problem with this is that huge numbers of rays are needed and/or much smoothing needs to be done to minimize the noise in the laser energy deposition. The first option can require much computation time, while the second option can smooth the nonuniformity features that the raytrace is intended to provide. In our new MPI implementation of 3D raytracing in the massively parallel FAST hydro code, we have experimented with different approaches to increase the speed of the raytracing while reducing the noise due to deposition from discrete rays. We will review these approaches and describe our progress.

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Linear plasma response, electrostatic fluctuations and Thomson scattering*

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Abstract
A nonlocal and nonstationary transport theory provides a method of solution of the initial value problem for the full set of linearized Fokker-Planck kinetic equations with Landau collision operators. The closure relations reduce the problem of finding particle distribution functions to the solution of the closed set of fluid equations. This has been recently realized for the electron-ion plasma in the entire range of particle collisionality [1]. We will discuss new complete results for $\varepsilon(k,\omega)$ in electron-ion plasmas.

The full description of the longitudinal plasma response is used in the derivation of damping and dispersion relations for electrostatic fluctuations such as Langmuir waves, ion-acoustic and entropy modes. Particle collision effects are rigorously accounted for. The Onsager's regression of fluctuations method is applied to derive dynamical form factor $S(k,\omega)$ and Thomson scattering (TS) cross-section from the set of fluid equations. The new theory of $S(k,\omega)$ is a generalization of the previous results [2] by including high frequency, plasma fluctuations and zero frequency entropy modes. Our results provide rigorous limiting expressions for different theories of the TS cross-sections in dense strongly coupled plasmas [3]. We will examine the importance of an entropy mode peak as the direct measure of ion temperature in TS experiments.

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TOPICS IN MODELING SRS AND ITS HOT ELECTRONS AS THEY OCCUR WITHIN IGNITION SCALE HOHLRAUMS

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We utilize a package within the Lasnex code that can generate Stimulated Raman Back Scatter (SRS) light within the hohlraum. The user can specify the amount of SRS backward propagating light, its frequency, and the density at which the process occurs. In addition, the user can specify how the remaining energy, which in reality resides initially within the electron plasma wave (EPW), is to be modeled. Choices for these models include a) ignoring the EPW and simply continuing to propagate the rest of the laser energy, b) local thermal energy deposition, and c) putting it into a super-thermal «hot electron» distribution. The level and spectrum of these hot electrons can also be chosen. Thus, for example, we can model either the main hot electron component of ~ 100 kJ at ~ 20 keV, or the «super-hots» of ~ 5 kJ and 60 keV. The hot electrons are transported in a diffusive, quasi isotropic manner. We present preliminary results using these various deposition models, reporting on observables such as capsule implosion symmetry, in-flight ablator thickness, and the x-ray spectrum emitted from the Au that has been bathed by the hot electrons. The need for our ability to model the hot electron transport more as beaming along the direction of the EPW is raised. We also describe other feedback loops that may result from the SRS light's effect on hohlraum plasma conditions, that can affect, for example, cross beam transport back at the laser entrance hole.

I prefer a poster presentation LLNL-ABS-552491

Tuesday, June 26^{th} 2012

Modeling and observation of after-bang radiative shocks on NIF

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In NIC indirect drive implosions, the pressure at stagnation can reach 100s of Gbar at the center of the compressed core. A strong outward going shock is then launched through a downward ramp of compressed ablator material (CH) until it breaks out through the ablation front and strongly radiates. A corresponding ring of emission is observed a few hundred picoseconds after bangtime. We will discuss the physics of this phenomenon and what it can tell about the implosion dynamics.

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The Phase of Hydrodynamic Growth in Inertial Confinement Fusion Capsules

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Understanding hydrodynamic mix is an important element in achieving ignition and gain on the National Ignition Facility. Defects on capsule surfaces can seed hydrodynamic instabilities, which can grow during the implosion and adversely affect capsule performance. These instabilities can come from shocks (Richtmyer-Meshkov) and accelerations (Rayleigh-Taylor). The interaction of these two instabilities during the early period of the implosion determines whether an exterior defect will grow inward or outward at peak implosion velocity and final compression. We examine how the capsule inner and outer surfaces work in tandem to determine this perturbation phase at peak-velocity in hydrodynamic simulations of multi-shock ignition designs.

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LLNL-ABS-552711

Magnetic Field Generation and Growth in Rayleigh-Taylor Unstable ICF Plasmas

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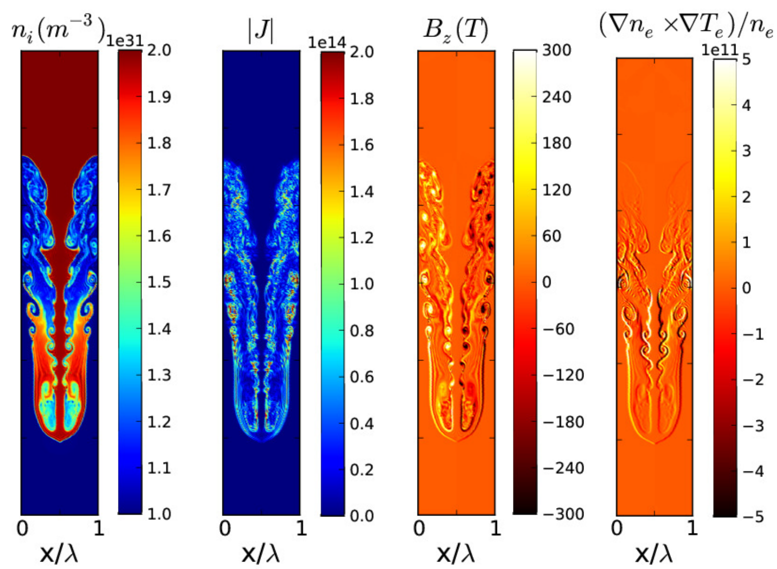
It has long been expected that Rayleigh-Taylor instabilities (RTI) in ICF implosions can generate magnetic fields. A plasma model that includes both ion and electron physics, Hall-MHD, is used to self-consistently study the generation and growth of magnetic fields in RTI. The Washington Approximate Riemann Plasma (WARPX) code that employs the Runge-Kutta discontinuous Galerkin method is used here. The Hall-MHD model contains some electron physics while assuming charge neutrality, neglecting electron inertia, and neglecting the speed of light.

Planar single-mode and multi-mode studies of RTI are performed in a stratified two-fluid plasma. The simulations are initialized such that a force balance exists in the system for both ions and electrons. Densities and pressures are initialized for ions and electrons with an initial perturbation applied to the density alone. Self-consistent magnetic fields are observed and these fields grow as the RTI progresses. Figure 1 presents results of the ion density (a), total current (b), the resulting out-of-plane magnetic field (c), and the term that drives the time derivative of the magnetic field (d) in a 2-dimensional simulation for late-time RTI. The out-of-plane magnetic field reaches magnitudes of $10^2 - 10^3$ T but it isn't large enough to affect the RTI evolution.



(a) (b) (c) (d)

Figure 1: Ion density in m^{-3} (a), Total current in A/m^2 (b), out-of-plane magnetic field in T (c), and $(\nabla n_e \times \nabla T_e)/n_e$ after $h/\lambda \approx 2$

The parameter regimes used are relevant to ICF and scaling studies are performed to determine how variations in density, acceleration, instability wavelength, and Atwood number affect the resulting magnetic fields. The studies performed will allow us to estimate the magnitude of the magnetic fields, and consequently, the Hall parameter that can be expected in ICF. Large Hall parameters can significantly reduce electron thermal conduction. An estimation of the potential impact on the electron thermal conductivity will also be provided.

High-Density Carbon (Diamond) Ablator for NIC Ignition Capsules

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We present our continued effort to improve ignition capsules with high-density carbon (HDC) ablators. HDC ablators show high performance based on simulations, despite the fact that integrated hohlraum simulations show that for the same peak Tr, the shorter pulse for HDC capsules results in higher M-band radiation compared to that for plastic capsules. HDC capsules have good 1-D performance because HDC has relatively high density (3.5 g/cc), which results in a thinner ablator, resulting in more radiation absorption. HDC ablators have good 2-D performance because the ablator surface is more than an order-of-magnitude smoother than Be or plastic ablators. Here we present two HDC ignition designs doped with W and Si, respectively. For the design with maximum W concentration of 1.0 atomic % (and respectively with maximum Si concentration of 6.0 atomic %): peak velocity = 0.395 (0.41) mm/ns, mass weighted fuel entropy = 0.463 (0.46) kJ/mg/eV, peak core hydrodynamic stagnation pressure = 690 (860) Gbar, ablator mass remaining at peak velocity = 5.1 (4.5) %, and yield = 16.3 (18.4) MJ. Refreeze of the ablator near the fuel region (cooling caused by the rarefaction launched at the ablator-fuel interface after the 1st shock passes this interface) can be avoided by appropriate dopant placement. 2-D simulations show that for the Si doped HDC ablator, yield is close to 80% YOC even with 2.5x of nominal surface roughness on all surfaces. The clean fuel fraction is about 75% at peak velocity. Currently, there are several on-going R&D efforts to provide the required engineering and physics basis for the fabrication and a more detailed design of the HDC ignition capsule: (1) to dope HDC with the required concentration of W and Si, (2) to develop a more accurate diamond equation of state, (3) to estimate the change in HDC melt temperature with the presence of dopant, and (4) to measure the shock uniformity using planar HDC targets. A first undoped HDC Symcap is scheduled to be fielded later this year.

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Silicon-Class Ablators for NIC Ignition Capsules

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We present design studies using silicon-class ablators (i.e., Si, SiC, and SiO_2) for NIC ignition capsules. These types of ablators have several advantages in that they: (a) require no internal dopant layers and are robust to M-band radiation; (b) have smooth outer surfaces – Si shells have the same outer surface roughness as diamond shells (more than an order of magnitude smoother, in power, than Be or plastic ablators), and the outer surface roughness for SiC shells is between that of diamond and plastic; (c) have stable fuel-ablator interface; and (d) have good 1-D performance – SiC ablator has high peak velocity and low entropy (e.g., peak velocity = 0.37 mm/ns, mass weighted fuel entropy = 0.42 kJ/mg/eV, ablator mass remaining at peak velocity = 5.3%, peak core hydrodynamic stagnation pressure = 800 Gbar, and yield = 20 MJ) and Si ablator has 1-D performance comparable to Be ablator but with higher stagnation pressure (~700 Gbar). SiO_2 was also considered but has low ablation efficiency. The major disadvantage for this class of ablators is the relatively short ablation scale length and low ablation velocity. Consequently, the ablator is more susceptible to breakup caused by RT instabilities. However, smoother outer surfaces on this class of ablators can reduce the effect of RT instabilities. Both 1-D and 2-D simulations will be presented.

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Energetic Electron Generation in Two-Plasmon Decay Instabilities in Direct-Drive Inertial Confinement Fusion

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We present a series of 2-D particle-in-cell (PIC) simulations using the full PIC code *OSIRIS* on the long-term (~10-ps) nonlinear behaviors of the two-plasmon-decay (TPD) instability for parameters relevant to inertial confinement fusion [Yan et al. Phys. Rev. Lett. **108**, 175002 (2012)]. When the TPD threshold is exceeded, the simulation results show that significant laser absorption and energetic electron (>50-keV) generation occur in the nonlinear stage. The energetic electrons are mostly forward oriented, which poses a preheating risk for targets. The hot electrons are stage-accelerated from the low-density region to the high-density region. New modes with small phase velocities develop in the low-density region after saturation. These modes can couple to background thermal electrons and form the first stage for electron acceleration. A fluid code has been developed to show that similar new TPD modes can develop under static ion-density fluctuations. In the PIC simulations the ion-density fluctuations are observed to be driven by plasma waves through the ponderomotive forces. Electron-ion collisions are shown to significantly reduce the efficiency of this acceleration mechanism.

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The Mitigating Effect of Electron–Ion Collisions on Hot-Electron Generation Caused by the Two-Plasmon-Decay Instability in Inhomogeneous Plasmas

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While the threshold for the onset of the two-plasmon-decay (TPD) instability in directly driven inertial confinement fusion targets is determined by the inhomogeneity scale length in the plasma density,[1] the nonlinear saturated state and subsequent hot-electron generation is shown to be sensitive to the level of collisional dissipation of the Langmuir waves and Landau damping of the ion-acoustic modes. A quasilinear-Zakharov model of TPD[2,3] is used to investigate the mitigating of effects of increasing the effective *Z* of the ablator material with regard to target preheat (CH, SiO_2 and Si ablators are considered with an effective *Z* of 5.3, 10.0, and 14.0, respectively). The partition of the total absorption between the anomalous absorption into thermal versus suprathermal electrons is discussed.

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Particle-in-cell Simulations of laser plasma interactions near the quarter critical surface

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We present simulation results on the laser-plasma interaction near the quarter critical surface under conditions relevant to inertial fusion. Under these conditions, the high frequency hybrid instability (HFHI) where the backward going daughter wave have mixed polarizations, is likely to be dominant. In high temperature plasmas where HFHI modes is dominant the absorption level can be high (up to 40%) for systems which are below the two plasmon threshold. This result implies, for laser pulses with a long (compared to the instability growth time, in the order of 1ps) rise time, the mixed polarization modes with small perpendicular wavenumber will play a even more dominant role. Other nonlinearities such as the generation of hot electrons, the generation of half harmonics, and the effects of overlapping beams will also be discussed.

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Hot Electron Generation by "Cavitating" Langmuir Turbulence in the Nonlinear Stage of the Two Plasmon Decay Instability.

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The kinetic reduced-description particle-in-cell (RPIC) simulation technique has been applied to study the nonlinear stage of the two-plasmon decay (TPD) instability in an inhomogeneous plasma driven by crossed laser beams. The TPD instability is found to be a prolific generator of "cavitating" Langmuir turbulence. Langmuir "cavitons"- localized longitudinal electric fields, oscillating near the local electron plasma frequency, trapped in ponderomotive density depressions - collapse to dimensions of a few electron Debye lengths, where the electric field energy is collisionlessly transferred to electron kinetic energy. The resulting hot electrons can attain energies up to 100 keV with net hot electron flux out of the system up to a few percent of the input laser energy. Scaling laws for this hot electron generation by TPD, in regimes motivated by recent experiments on the Omega laser, will be presented. The present presentation concentrates on the microscopic mechanisms for hot electron generation. The spatial distribution of the maxima of the electric field envelope modulus is found to be very spiky, with the distribution of electric field envelope maxima obeying Gaussian statistics. The cavitons are produced in density depletion trenches produced by the combined ponderomotive interference of the crossed laser beams and the ponderomotive beats of the primary backward-going TPD Langmuir waves resulting from the crossed beams. The Langmuir turbulence is strongest in the electron density region $n_e=0.241n_c$, where the forward Langmuir waves (LWs) from the crossed beam TPD are degenerate. Nucleation of cavitons is assisted by the modulation of the electron density in the trenches by the beating of the common forward going LW and the pair of backward going LWs. The correlation of electric field envelope maxima and electron density minima is found to be strong in the spatial region of strongest LW activity referred to above and, in this region, the correlation is confined to the trenches. Ponderomotive modification of the averaged density profile introduces long time scale modulation of the induced turbulence. The auto correlation function of the LW envelope field provides the shape near the stronger caviton electric field envelope maxima using a theorem for Gaussian random fields. The hot electron temperature is found to be approximately a linear function of the "caviton temperature" determined from the Gaussian distribution of caviton maxima. These diagnostics provide strong evidence for the importance of Langmuir caviton collapse in the generation of hot electrons by TPD. Extended Zakharov model predictions for TPD exhibit the same qualitative phenomena. Temporal power spectra of the high frequency electric field envelopes associated with collapsing cavitons have significant contributions at frequencies near and below the local electron plasma frequency, another signature of Langmuir collapse. An important advantage common to RPIC and ZAK for this study is the natural separation of high and low frequency fluctuations by using an envelope representation for the electric fields.

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Escape Trajectories from Traditional Condensed Matter

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We are entering a golden age of facility capability and user access for the preparation of extreme states of matter. While the campaign for ICF is both a major driver and a central highlight of this era, the entire achievable phase space of temperature, density, and magnetic field (among other variables) is rich with scientific opportunity. Here, I focus on the transition regimes from 'traditional' condensed matter to dense plasma and 'warm dense matter' (WDM) states. First, I will survey the physical phenomena already observed, already predicted, or that can be reasonably expected at temperatures up to a few tens of eV for solid-like and higher densities. Among other examples, this will include electride behavior, strongly nonequilibrium x-ray or UV FEL-driven states, the warm-dense chemistry of planetary cores, and some speculations about the importance of warm-dense surface science. Second, I will discuss experimental and theoretical developments relevant for improved experimental diagnostics of such extreme states of matter – the issue of sensitive, reliable diagnostics of state variables and structure is, in and of itself, a major scientific challenge. Emphasizing the commonality of synchrotron- and laser-facility-based diagnostics, I will address several opportunities for cross-fertilization between these two x-ray science communities. In this context, I will discuss my group's work on inelastic x-ray scattering science and instrumentation, and our ongoing collaborations to improve the theoretical treatment of condensed phase effects in WDM thermometry.

Collisional effects on hot electron generation in the two-plasmon decay instability in inertial confinement fusion

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Abstract

Recent study on two-plasmon-decay (TPD) [R.Yan et al, Phys. Rev. Lett, **108**, 175002 (2012)] showed that collisions can significantly reduce hot electron generation. Here we present further study on how collisions reduce TPD hot electron generation under different laser intensities, using the PIC code OSIRIS and the fluid code LTS. In particular we study how collisions can suppress the new TPD modes that only appear in the nonlinear stage in the lower density region. Previous study found that these new modes were generated from ion density fluctuations and formed the first stage for electron acceleration due to their low phase velocities.

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ALADIN: A kinetic electron model for validating electron transport modeling in hydrodynamics codes

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Electron transport in laser-produced plasmas is a key issue since the beginning of laser-plasma interaction physics. It is well kown that in many situations, the electron conductivity based on local theories, such as Spitzer's or Braginskii's, failed to reproduce the experimental observations. Many studies enlighted the necessity of a kinetic description along with Maxwell's equations (see the reference [1] for a review). But, such a modeling was difficult to implement in radiative-hydrodynamics (RH) codes. Usually, the use of an *ad hoc* flux limiter in RH modeling allows to reproduce partially the experiments. Although in many simulations this limiter is fixed for a given run, this flux limiter should be time and space dependant. This approach is clearly not satisfying, particularly when applied to complex plasmas such as those produced in an ignition hohlraum.

In order to improve the electron transport modeling in RH codes [2,3], it is possible to account for the non-local electron behaviour and the generation of magnetic fields, by taking into account kinetic effects in the usual local description, in a rather simplified way, coupled to a magnetic-hydrodynamics modeling. But such a description needs to be validated by a kinetic modeling in order to assess the results. We have developped the ALADIN code, a bidimensional electron Fokker-Planck code coupled to Maxwell equations. Our modeling has been implemented using an implicit method. We will present some comparisons between ALADIN and the FCI2 RH code on various conditions, including those reported in [4].

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Ion Fokker-Planck simulation of D-^{3}He gas target implosions

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The question of accurately rendering the nuclear reaction yields observed in a set of implosion experiments involving D-^{3}He gas-filled microballoons recently performed on the OMEGA laser facility [1] has drawn considerable attention lately [2]. The discrepancies found between expected and measured yields as the relative abundances of D and ^{3}He are varied have been tentatively attributed to a sedimentation, or stratification phenomenon occurring in the target core [2],[3].

In this work, we investigate the possibility of ion species sedimentation in a detailed way through ion-kinetic simulations of the implosion process using our Vlasov-Fokker-Planck code FPion [4]. In these calculations, the D-^{3}He gas is treated as a mix of two different ion specii, each with its own velocity distribution function, using a boundary condition applied at the fuel-pusher interface. The latter is extracted from a previous fluid simulation of a hydrodynamically equivalent system using the hydro code LILAC [5]. A noticeable amount of segregation is found to build up during the main shock propagation to the target center, but its evolution as implosion proceeds is more complex than the situation prevailing in a stationary shock front, which is a rather natural extension of the results of Ref. [6]. More details will be given in the presentation.

The question of whether these effects might occur in full-scale ignition ICF targets is also examined through two-ion-species FPion simulations of the DT implosions which were discussed in the single-species frame in Ref. [4].

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Poster presentation preferred

High Energy Density Plasma Created and Investigated by an X-ray Free Electron Laser

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With an advent of X-ray free electron lasers (FEL) [1], ultrafast (< 100 fs) and high-intensity (> 10^{17} W/cm^2), which were previously the domain of optical lasers, are now available in the X-ray regime. The bright monochromatic X-ray radiation has a great potential to create and diagnose unique states of high energy density (HED) conditions. In the experiment performed at the Linac Coherent Light Source (LCLS) at SLAC National Accelerator Laboratory, an intense 80 fs X-ray pulse at 10^{17} W/cm^2 with photon energies near aluminum K absorption edge (1560 eV) is focused on a 1μm thick Al foil, and K-alpha emission spectra are observed. Due to the long penetration depth and the ultrashort duration of X-ray pulse, a uniformly heated dense (T_e ~ 100 eV, ϱ = 2.7 g/cc) aluminum plasma can be created by the isochoric heating of solid target. With the FEL photon energies not only above the K-edge of a solid aluminum, but also *below* the K-edge where X-ray energy is not sufficiently high to direct excite the 1s state, a significant absorption of X-FEL pulse and the copious K-alpha emission spectra are observed. They indicate the new interaction channels of intense X-ray and matter, which were not accessible with conventional X-ray sources, are created. Rich spectra of such channel are simulated using the collisional-radiative code, SCFLY. The pertinent physics of the intense X-ray - matter interactions and the effect of opacity of hot dense plasma will be discussed.

REVERSE RADIATIVE SHOCK LASER EXPERIMENTS ON OMEGA-60

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We present the results from high-energy-density laboratory astrophysics experiments that explore the hydrodynamic and radiative properties of a reverse shockwaves. In this context, a reverse shock is a shock wave that develops when a freely flowing, supersonic plasma is impeded. In our experiments, performed on the Omega-60 laser facility, 10 beams are used to accelerate a Sn plasma ejecta through vacuum into an Al plate in front of which a shock forms in the rebounding plasma. We will discuss the experimental design and available data with complementing CRASH (van der Holst et. al, 2011, ApJS, 194, 23) simulations.

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Plasma jets produced by low energy laser pulse interaction with planar and crater targets

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Abstract

Laser experiments of plasma jet formation using low energy nanosecond laser pulses, below 20 J, are presented. Planar and crater gadolinium and aluminum targets are irradiated by laser intensities of several 10^{14} W/cm^2. Spatially-resolved time-integrated X-ray spectra were recorded in the spectral range from 7 to 10 Å. A jet like structure is obtained from crater aluminum targets, which is not seen in planar targets irradiation. For gadolinium a jet is observed from both planar and crater targets, suggesting that the collimation is due to radiative cooling.

Two-plasmon-decay turbulence driven by the shared-wave triad of two crossed beams*

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We simulate the saturation of the two-plasmon decay (TPD) instability in an inhomogeneous plasma driven by two crossed laser beams by solving the extended Zakharov model equations numerically in two dimensions. Each laser beam drives two pairs of daughter TPD Langmuir waves (LWs) symmetrically in k-space about the beam's wave vector. At a particular density (a function of the electron temperature and of the angle between the two beams), the two crossed beams drive a common TPD LW. This common wave and the two associated TPD daughter waves comprise a "triad mode." Because of the shared wave, the waves in the triad mode are more strongly driven than any isolated TPD pair and so set the threshold for crossed-beam TPD instability. Properties of the triad mode underlie the saturated turbulence, affecting the nature of caviton nucleation and collapse, with implications for hot electron production. The Zakharov simulation results compare in qualitative detail with reduced particle-in-cell (RPIC) simulations (see H.X. Vu et al., oral presentation, this meeting).

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Study of Laser Plasma Interactions at Intensities of Interest to Shock Ignition Targets Using OSIRIS

F. S. Tsung, M. Tzoufras, A. Tableman, B. Winjum and W. B. Mori, UCLA.

In shock ignition for ICF laser plasma interactions play the crucial role of converting the laser energy to hot electrons in the under-dense plasma thereby determining the shock structure deep in the target. To quantify the effect of LPI on realistic shock ignition targets we performed a study using 1D and 2D PIC simulations. In 1D, the primary absorption mechanism is **S**timulated **R**aman **S**cattering (SRS) near the quarter critical surface and also rescatter of the backscattered light near the 1/16-th critical surface which can produce energetic electrons in the backward direction. In 2D, both SRS and the **T**wo **P**lasmon **D**ecay instability/**H**igh **F**requency **H**ybrid **I**nstability can be excited by the laser, therefore the hot electron spectrum and the absorption is different than those in 1D. The spectrum of the energetic electrons, the partition of the incident laser energy into forward going electrons, backward going electrons, and reflected laser light will be shown as a function of intensity for both 1D and 2D cases.

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Poster preferred

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Thomson-Scattering Measurements of Ion-Acoustic Wave Amplitudes Driven by the Two-Plasmon Decay Instability

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Thomson scattering was used to measure enhanced ion-acoustic waves (IAW's) driven by the two-plasmon-decay (TPD) instability. The IAW amplitude scales with TPD signatures ($3/2\omega$ and hot-electron generation). *QZAK*[1–3] modeling investigates the mechanism for IAW growth; two potential explanations are the beating of electron-plasma waves (EPW's) to create ion density perturbations and the Langmuir decay instability. These processes have been shown through simulations to be saturation mechanisms for TPD. Up to 20 beams with 860-μm-diam laser spots generated by 2-ns-long pulses of 3ω (0.351-μm) (Ref. 4) light with overlapped intensities up to 4×10^{14} W/cm^2 were used to produce ~300-μm density-scale lengths. The planar CH targets were backed with Molybdenum and the K_α yield was used to determine the fraction of laser energy converted into hot electrons. The IAW amplitudes were measured using 4ω Thomson scattering near 3ω quarter-critical densities. Time-resolved $3/2\omega$ spectroscopy was used to compare the amplitude of $3/2\omega$ emission to the IAW amplitude.

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PIC Simulations of the Interaction of Stimulated Raman Scattering in Neighboring Laser Speckles*

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Stimulated Raman scattering (SRS) is a threat to the successful operation of the National Ignition Facility (NIF). The laser beams at NIF consist of a distribution of high-intensity hot spots, or speckles, with a percentage of speckles above threshold for SRS. While particle-in-cell (PIC) simulations (using OSIRIS and other codes) have predominantly simulated SRS in single speckles, we (and others) have begun investigating large-scale simulations covering many-speckle lengths and widths. Diagnosing SRS in systems with many speckles requires diagnosing an ensemble of potentially interacting elements. Here we present simulations from a focused study of the interaction of two co-propagating speckles in 2D, with one speckle above threshold and one below threshold. The above-threshold speckle can seed SRS in the neighboring below-threshold speckle via 1) scattered light that seeds SRS, 2) plasma packets that seed SRS, and 3) hot electrons that reduce the plasma wave damping rate and facilitate SRS growth. In backscattering, the scattered light wave travels backward and the plasma wave travels forward relative to the laser propagation direction, while a distribution of hot electrons may be generated sideways by side-loss out of plasma waves. We isolate the three mechanisms for speckle interaction by varying the speckle positions relative to each other and by crossing speckle polarizations in scenarios where we want to limit interactions via scattered light. We present results for which these three mechanisms cause SRS to grow in the below-threshold speckle.

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Wednesday, June 27th 2012

Saturation of multi-beams laser plasma interactions by turbulent ion heating

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The overlapping beat waves produced by multiple pairs of laser beams crossing in ICF plasmas can lead to turbulent heating of the ions. The ion temperature increase can be very significant for NIF conditions (~few x), which saturates the cross-beam energy transfer and prevents the re-amplification of SBS produced inside the target by the incoming laser beams.
We use a 3D test particle code to make quantitative estimates for NIF targets entrance holes conditions, where 24 quadruplets of laser beams overlap in a ~mm^3 scale plasma, generating 276 beat waves with fixed phase velocities (determined by the laser beams' wavelengths and pointings). Particles trajectories are calculated by integrating the equations of motion, while the 276 electrostatic potentials are self-consistently calculated from the plasma susceptibility via the non-Maxwellian distribution function of particles. A binary collisions model is also included.
Calculations show the formation of a high-energy tail in the ion distribution function, due to a mix of trapping and quasi-linear diffusion processes. At later times, collisions restore the energy from the hot ions back into the low-velocity bulk, leading to an equilibration towards a high temperature drifting Maxwellian distribution. The ion temperature increases from ~1 to ~4 keV, leading to a ~4-5x reduction of linear gains for cross-beam energy transfer. Other hydrodynamics effects resulting from the turbulent heating, such as hole closure, will also be discussed.
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Mitigation of Cross-Beam Energy Transfer in Direct-Drive Plasmas

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Cross-beam energy transfer (CBET) in direct-drive implosions is observed to reduce the hydrodynamic efficiency of the laser drive. The outer rays of each beam interact through the ion-acoustic waves to extract energy from the central rays of each beam. This accounts for an ~10% loss of absorption which results in an ~20% reduction in hydro-efficiency as measured by the scattered light and x-ray bang time. Experiments that reduce the laser energy in the outer rays by reducing the ratio of the laser spot size to target diameter to $R_{\text{beam}}/R_{\text{target}} = 0.7$ eliminate CBET and significantly increase the hydrodynamic coupling, but the reduction in laser spot size leads to irradiation nonuniformities and significant uniformity growth. To mitigate CBET and maintain sufficient illumination uniformity, a two-state zooming is proposed. During the critical time for seeding nonuniformities, before a significant conduction zone is produced, the radii of the laser beams are equal to the target radius $\left(R_{\text{beam}}/R_{\text{target}} = 1\right)$, minimizing the nonuniformities. Once the plasma has sufficiently expanded, the radii of the laser beams are reduced $\left(R_{\text{beam}}/R_{\text{target}} = 0.7\right)$, minimizing CBET. The increase in transverse thermal conduction will smooth the low-mode intensity nonuniformities producing a uniform drive. Initial 2-D hydrodynamic simulations of OMEGA direct-drive experimental conditions indicate that transitioning to smaller laser spots after the picket pulses does not increase the low-mode nonuniformities. The combination of zooming and dynamic bandwidth reduction (removing smoothing by spectral dispersion during the drive) will provide a 30% effective increase in the drive energy in OMEGA direct-drive implosions.

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Mitigation of Cross-Beam Energy Transfer in Polar-Drive Implosions

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Direct-drive experiments on the National Ignition Facility require use of the non-spherically symmetric indirect drive beam layout. In polar-drive (PD), the power and pointing of the cylindrically symmetric NIF beams are optimized to uniformly implode and capsule. As beams refract and cross each other in the coronal plasma, cross-beam energy transfer (CBET) can cause laser energy to "bypass" the high-absorption region of the plasma near the critical surface. Recently designed DPP's for optimized PD will soon be available on OMEGA for experiments leading up to PD implosions on the NIF. The effect of CBET is modeled for these PD implosions on OMEGA. Three-dimensional paths and crossings of all beams are calculated using *DRACO* hydrodynamic code predicted plasma profiles. CBET is modeled for each of the beam rings. The equatorial third ring suffers the most from CBET, but the reduction in total absorption (~10%) is similar to the 60-beam symmetric illumination case. For all rings, power is preferentially removed from the inner portion of the beam profile and a potentially perturbing structure is created in the effective beam profile. Strategies for mitigation of CBET in PD implosions are explored. The most-promising strategies are wavelength shifting the beam rings and two-stage zooming. Wavelength shifting the beam rings with respect to each other can be used to control the flow of power between the rings. The laser absorption of the rings can be balanced or energy "funneled" to a specific ring. In two-stage zooming spot sizes nominally equal to the target radius are used during pickets, while smaller spot sizes are used for the main drive. Larger spots during the pickets impose smaller nonuniformities on target. Smaller spots during the main drive reduce CBET when it is most detrimental to absorption. *DRACO* simulations and CBET modeling suggest that good implosion symmetry can be maintained while CBET is greatly reduced.

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Prefer oral session.

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The Resurgence of Stimulated Brillouin Scattering from NIF hohlraums

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(Dated: April 30, 2012)

Before the first NIF experiments in 2009, stimulated Brillouin scattering was expected to scatter a significant fraction of the 44° and 50° beams, the "outer" beams that propagate to the hohlraum wall without significant absorption in the helium gas fill. However, only 1% or less of the outer beams power has been backscattered for almost all shots. The principal reasons are (1) that the pre-shot rad-hydro modeling produced a larger, hotter gold plasma than the more accurate modeling currently used does and (2) about 30% of the outer beam power to transferred to "inner" beams that interact little with the gold wall plasma. Recent experiments with longer ($\sim$ 22ns), lower peak power ($\sim$ 320TW) laser pulses have measured about 10% SBS backscatter over the last nanosecond. We model these results with pF3D simulations.

SBS has also been measured at significant levels, albeit still smaller than SRS, from the inner 30° and 23° beams when the laser intensity due to cross-beam power transfer or increased incident laser power exceeds thresholds. The amount of SBS is sensitive to the details of the cross-beam power transfer, to the level of SRS, to the laser pulse length, and to the capsule ablator material. PF3D modeling can explain many of these experimental features.

Capsule ablators, such as Beryllium and Diamond, are now being designed for NIF experiments. Using the new rad-hydro modeling and pF3D simulations, we will present our expectations for SBS for these designs.

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Self-organized bursts of coherent stimulated Raman scattering and hot electron transport in speckled laser plasma media

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Stimulated Raman Scattering (SRS) continues to be a laser plasma instability of concern for laser-driven fusion experiments. In SRS, incident laser light scatters resonantly from density fluctuations (electron plasma waves) in the plasma. High levels of backscatter reduce the coupling of laser energy to the fusion target and place stringent constraints on implosion symmetry and other design parameters. Recently, the key nonlinear physics governing SRS onset and saturation has been identified in speckled laser plasma media. Hot electrons from intense speckles, produced during SRS daughter electron plasma wave bowing and filamentation, seed and enhance the growth of SRS in neighboring speckles by reducing Landau damping. Trapping-induced nonlinearity and speckle interaction through transport of hot electrons, backscatter, and sidescatter SRS waves enable the system of speckles to self-organize and exhibit coherent, sub-ps SRS bursts with more than 100% instantaneous reflectivity, consistent with an SRS transverse coherence width much larger than a speckle width [1]. Furthermore, SRS reflectivity saturates above a threshold laser intensity [2], a level of reflectivity that depends upon $k\lambda_D$: higher $k\lambda_D$ (e.g., through raising electron temperature) leads to lower SRS. We are exploring the efficacy of a novel approach to lowering SRS by raising $k\lambda_D$ in NIC capsules. This is accomplished through the use of high-Z dopant in the fill gas that increases inverse bremsstrahlung heating of the hohlraum plasma to raise $k\lambda_D$; or, one might apply a large (~10T) external magnetic field in order to reduce thermal conductivity and thus raise the plasma temperature.

* LANL Guest Scientist.

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Studying counterstreaming high velocity plasma flows relevant to astrophysical collisionless shocks

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In a broad range of low-density astrophysical plasmas the flow velocity is very high, making the ion-ion collisional mean free path very large compared to the scale lengths of various observed astrophysical shocks. These shocks are believed to be "collisionless," driven by plasma instabilities and self generated magnetic fields. A series of experiments at the Omega laser facility are underway to study the formation of collisionless shocks under scaled laboratory conditions, using high velocity counterstreaming and interpenetrating plasma flows. Double CH_2, pure carbon, and beryllium foils have been irradiated with a laser intensity of ~10^{16} W/cm^2. The laser-ablated plasma was characterized 4 mm from the foil surfaces, using Thomson scattering at a position located directly between the two foils. Significant increases in electron and ion temperatures were seen for all three target materials in the counterstreaming case, compared to a single flow in isolation. Planned follow-on NIF experiments will also be described. Prepared by LLNL under Contract DE-AC52-07NA27344.

Theory and Validation of Electron-Ion Thermal Relaxation in Fusion and Astrophysical Plasmas

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We describe a model for the rate of thermal relaxation between electrons and ions in dense plasmas that includes the effects of particle screening and correlations, and quantum diffraction and degeneracy for electrons. The model resolves the close and distant particle encounters in a self-consistent fashion without the use of *ad-hoc* cutoffs in a generalized Coulomb log ($\ln \Lambda$). This is done by calculating the work done on the ions, which remain classical, by the ionic and electronic density fluctuations using a linear response model that takes advantage of the plasma susceptibilities and f-sum rule [1]. We validate the model (red lines in Fig. 1) in the classical regime using molecular dynamics simulations (diamonds) to span the weakly to moderately coupled plasma regimes as defined by particle correlations through the ratio g of the Landau to Debye lengths [2]. The simulations use the exact Coulomb force and avoid recombination by employing like charges for electron and ions since thermal relaxation is independent of their signs. We compare our generalized formula with previous results (black & blue lines) and describe the implications for ignition experiments on NIF. Similar results for electron thermal conductivity are expected and will be discussed with respect to NIF, including the effect of self-generated magnetic fields in the Rayleigh-Taylor mixing zones.

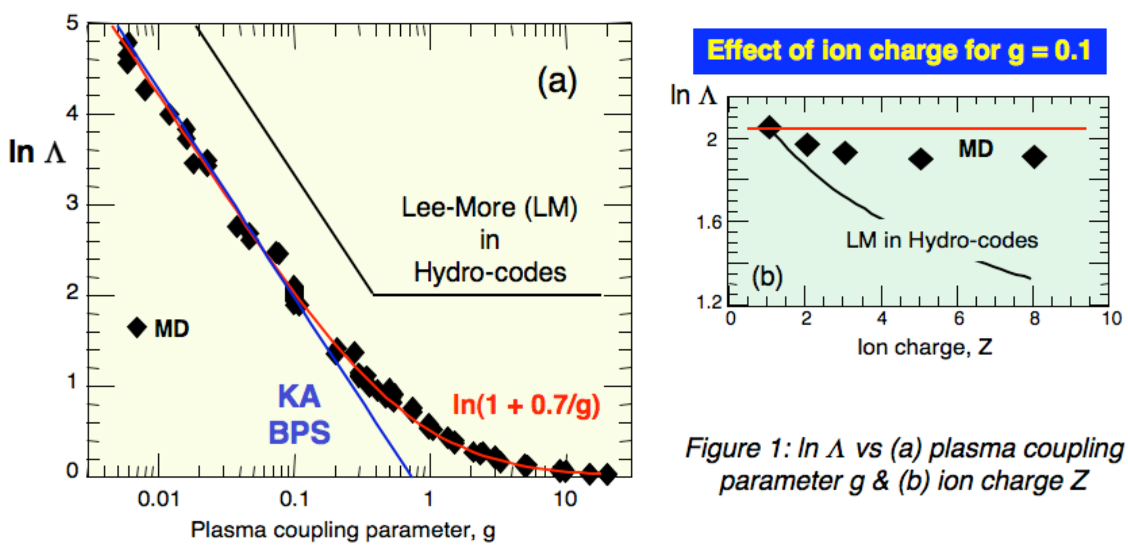

Figure 1: ln Λ vs (a) plasma coupling parameter g & (b) ion charge Z

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Particle acceleration by an intense laser pulse with complex target

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Particle beams produced by intense laser-foil interaction have many advantages, such as compact size, short duration and high energy density. These characteristics make them very appealing for many novel applications, i.e., ion-beam tumor therapy, proton imaging, injectors for standard accelerators, ion-beam ignition in inertial confinement fusion, etc.

In this talk, we propose a complex target (CT) configuration for generating high quality proton beams at moderated laser intensities. As showed in Fig. 1(a), the CT consists of two elements: a shaped thin foil (STF) and a backside inhomogeneous plasma layer (IPL). The STF is employed to compensate for the transverse laser profile. The IPL can be fabricated by inducing thermal expansion of a mass-limited foam target using a low-intensity laser. The IPL prevents the laser penetrating through the accelerated STF during the radiation pressure acceleration and suppress the negative effects of the thermal electrons.

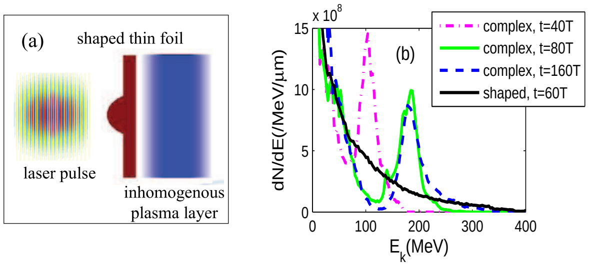

FIG. 1: (a) Schematic of the proposed complex target structure. (b) Energy spectrum of protons from 2D PIC simulations.

For the simulations, we use a parallelized two-dimensional particle-in-cell code[1]. The total simulation box is $120\lambda(x) \times 50\lambda(y)$, where λ is the laser wavelengths. This corresponds to a grid of $12000(x) \times 500(y)$. The distribution of the STF thickness is given by $l = max\{l_1, l_0 \exp(-y^2/\sigma_T^2)\}$, where $l_1 = 0.15\lambda$, $l_0 = 0.1\lambda$ and $\sigma_T = 6\lambda$. The STF is located in the region $19.85\lambda \leq x \leq 20\lambda$ with the density of $60n_c$, where $n_c = \omega^2 m_e/4\pi e^2$ is the critical density. The STF plasma consists of electrons and protons with charge-mass ratio $q_p/m_p = e/1836m_e$. The IPL located in the region $20\lambda \leq x \leq 80\lambda$, consists of electrons and heavy ions with charge-mass ratio $q_i/m_i = e/3672m_e$. It has a trapezoidal density profile with $20\lambda - 20\lambda - 20\lambda$ (linear growth-plateau-linear decrease) in x direction and the maximum density is $8n_c$. The initial electron temperature of the STF and the IPL is $1keV$. The normalized amplitude of the incident circularly polarized (CP) laser pulse is $a = a_0 \exp(-y^2/\sigma_L^2)$ with $a_0 = eE_0/m_e\omega c = 20$ and $\sigma_L = 8\lambda$. This corresponds to the laser intensity of $I = 1.1 \times 10^{21} W/cm^2$ for the wavelength $\lambda = 1\mu m$. The pulse has a also trapezoidal temporal profile with $5T - 30T - 5T$, where $T = \lambda/c$ is the laser period.

The energy spectrum of the accelerated protons are shown in Fig. 1(b). The spatial distributions of the SFT proton density and the laser intensity are shown in Fig. 2.

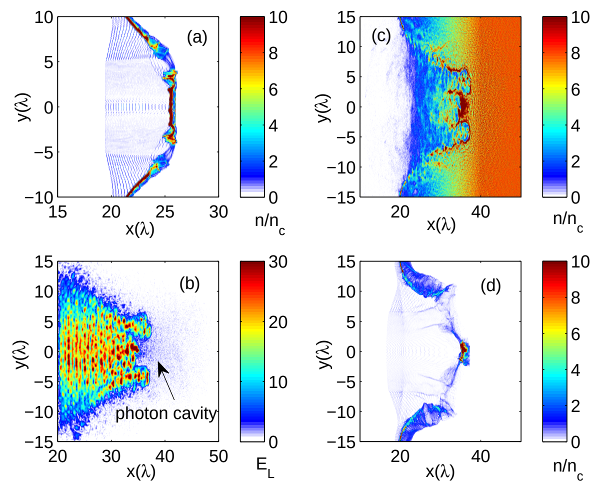

FIG. 2: Spatial density distribution of the SFT protons at (a) $t = 40T$ and (d) $t = 60T$. (b) Spatial distribution of the laser intensity $E_L = \sqrt{E_y^2 + E_z^2}$ at $t = 60T$. (c) Spatial density distribution of the electrons at $t = 60T$.

By using a CT configuration we have improved both the monochromaticity and collimation of the accelerated protons. The STF, compensating for the transverse laser profile, makes the proton acceleration more stably at early times. The IPL enhances the qualities of accelerated protons by stabilizing the proton cavity, providing hole-boing supplementary acceleration and suppressing the subsequent thermal expansion effects. By optimal matching, we show that a collimated, hundreds MeV monoenergetic proton beam can be produced by a CP laser pulse at $10^{21} W/cm^2$ intensity incident on the CT. The improvement of the proton beam quality will be beneficial and important for applications.

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Anomalous laser absorption by synchrotron radiation and pair production in the ultra-relativistic regime

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April 27, 2012

Laser intensity has now reached 10^{22}W/cm^2 [1] and is expected to reach 10^{23}W/cm^2 [2] within the next five years. The increasing importance of energy loss due to synchrotron emission and eventually pair production as we go further into this "QED-plasma physics" regime requires a reevaluation of the way we model laser plasma interactions. Particle-In-Cell (PIC) simulations are well suited to simulating ultra-relativistic particle dynamics and the PIC code EPOCH [3] has been extended to include a semi-classical model for the synchrotron emission and the production of electron-positron pairs [4].

EPOCH has been used to simulate the effect of including synchrotron emission and pair production on laser interactions with relativistically underdense and overdense solid targets. In underdense targets a novel absorption mechanism is found based on strong synchrotron emission from electrons reinjected into the laser by the space charge field they generate at the front of the laser pulse. This absorption mechanism absorbs about 1% of the laser energy at 10^{22}W/cm^2 and can absorb up to 25% of the laser energy at higher intensities.

At intensities above 10^{23}W/cm^2 QED effects on relativistic hole-boring in overdense solids both reduce hole-boring efficiency due to highly efficient laser absorption into gamma rays but also offers the possibility of producing dense pair plasmas in the lab with next generation laser facilities.

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Thursday, June 28^{th} 2012

Simulations of Cone-in-Shell Targets for Integrated Fast-Ignition Experiments on OMEGA

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Integrated cone-in-shell fast-ignition experiments on OMEGA will benefit from improved performance of the OMEGA EP laser, including higher contrast, higher energy, and a smaller focus. A new target design will be used with a low-*Z* aluminum cone tip, which is expected to significantly reduce the scattering losses of fast electrons. Simulations of cone-in-shell targets using the radiation–hydrodynamic code *DRACO* are presented. Our simulation capabilities were significantly improved over the last year. Radiation transport has been included, the Eulerian scheme was improved by using proper Coriolis force terms, 3-D laser ray-trace has been included, and cross-beam energy transfer was accounted for. *DRACO* simulations of the previous target design show that a 15-μm-thick tip of the gold cone is breached by the strong shock from the implosion about 100 ps before the bang time and 280 ps before the time of peak compression. A new target design uses a 60-μm-thick aluminum block mounted in front of a gold cone. A very thin (~2-μm) gold layer inside the cone tip serves as a mounting layer for the block and also helps to shield the radiation. *DRACO* simulations predict that this design is more resilient against the shock than the previous gold-only design and the cone tip breakout is delayed by about 100 ps. Simulations of core heating by fast electrons generated by the OMEGA EP pulse using the hybrid particle-in-cell code *LSP* integrated with *DRACO* will be presented. The electrical resistivity mismatch between the aluminum tip and the surrounding plastic plasma is shown to collimate fast electrons into the assembled fuel. Energy deposition of fast electrons in the compressed core is investigated. Core heating and neutron yield are computed.

This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement Nos. DE-FC52-08NA28302, DE-FG02-05ER54839 and DE-FC02-04ER54789, 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.

Magnetic Guiding for Electron Fast Ignition

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We report on recent efforts[1] to find efficient schemes for electron-driven fast ignition. The modeling uses the hybrid-PIC code Zuma, coupled to the radiation-hydrodynamics code Hydra. Full-PIC modeling of the short-pulse laser-plasma interaction is separately done to generate a fast electron source injected into Zuma. The fast-electron energy needed for ignition is many times the deposited heat required. This is due to the electrons being too energetic to fully stop in the hot spot, as well as their large angular divergence. Electric and magnetic fields found using a resistive Ohm's law ($E = \eta J$) improve the coupling of a collimated source to the fuel. Non-resistive terms, such as $E = -(\nabla p_e)/en_e$, reduce the coupling, as reported by others[2]. A hollow magnetic pipe, which becomes large at a radius outside the initial electron source, can confine the electrons without causing magnetic mirroring due to field non-uniformity. We have stressed an axial field, which can be assembled from an imposed seed field in the fuel implosion[3], while others have studied azimuthal fields, which can be self-generated by the electrons transiting a transverse resistivity gradient[4]. For the same field envelope, an azimuthal field performs better than an axial one. The sign of the axial field also matters, even though electron orbits should be equivalent in both fields. This is due to different evolution of the magnetic fields, which requires non-resistive terms in Ohm's law. Rad-hydro simulations related to assembling magnetic pipes, or the structures needed to generate them, will be discussed.

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Abstract for Anomalous Absorption Conference, June 25-29, 2012, Key West, FL

Time-resolved study of hole boring at relativistic intensities in front of solid targets

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The evolution of plasma density profile during relativistic laser-plasma interaction in front of solid targets is studied by a novel single-shot time-resolved diagnostic. Measurements of the spectral shift in the specular light show a red shift decreasing over time corresponding to continuous weakening of ponderomotive pushing, indicating that on picosecond time scale the hole boring is slowed down by plasma pressure created by the laser itself in the ultra-relativistic regime. On-shot full characterization of the laser pulse enables simulations of the experiment without any free parameters. Two-dimensional (2D) Particle-In-Cell (PIC) simulation results agree well with the time resolved measurements and support the interpretation.

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Channeling of relativistic laser pulses in underdense plasmas and subsequent electron acceleration

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Abstract

The interaction of high energy relativistic laser pulses with underdense plasmas has been extensively studied in experiments and by simulations [1]. We present results of 3D PIC simulations and the corresponding theoretical analysis of relativistic self-focusing, laser pulse channeling, surface wave generation and electron acceleration [2]. Specifically, we study the interaction of laser pulses having their intensity I λ^2 in the range [10^{19}, 10^{20}] W/cm^2 μm^2, focused in a plasma of electron density n_0 such that the ratio n_0/n_c lies in the interval [10^{-3}, 10^{-1}], n_c denoting the critical density.

For laser pulse powers above the threshold for channeling, we have observed the stable laser pulse propagation as a single mode in an electron free channel as predicted in Ref. [3], in the limit of sufficiently underdense plasmas, namely for $n \leq 0.1\ n_c$. These results apply to picosecond laser pulses, and a very good agreement has been observed between the stationary analytical theory predictions [3] and our PIC simulations.

The steepen laser front is observed to give rise to a surface wave [4], which propagates along the sharp boundaries of the electron free channel created by the laser pulse. The mechanism responsible for the generation of the fast electrons observed in the PIC simulations is then analyzed by means of a test particles code. It is found [2] that the fast electrons are generated by the combination of the acceleration by the surface wave and of the betatron process [5]. The maximum electron energy observed in the simulations with I $\lambda^2 = 10^{20}$ W/cm^2 μm^{2}and $n_0/n_c = 2\text{x}10^{-2}$ is 350 MeV.

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Laser hosing in relativistically hot plasmas

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Recently-available kJ short-pulse lasers not only have the intensity to make electrons in a plasma oscillate at relativistic speeds but also have the energy to heat these electrons to relativistic temperatures. The mass of a fluid element can increase from its thermal energy as well as its fluid motion. Laser-plasma interactions in this regime are not well explored. Here equations for the laser envelope and plasma density evolution, both in the electron plasma wave and ion acoustic wave regimes, are re-derived from the relativistic Vlasov equation to include the plasma temperature effect. These equations are then used to study short-pulse and long-pulse laser hosing instabilities with a variational method approach. The analysis shows that a relativistic electron temperature reduces the hosing growth rates and shifts the most unstable modes to longer wavelengths. These results give a better explanation to the hosing instability observed in recent particle-in-cell simulations for laser channeling in fast ignition [Li et al., Phys. Rev. Lett. **100**, 125002 (2008); Phys. Plasmas **18**, 042703 (2011)] and experiments [Najmudin et al., Phys. Plasmas **10**, 438 (2002)]. They are also useful to understand laser-plasma instabilities in plasmas with relativistic electron temperatures.

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42nd Annual Anomalous Absorption Conference
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On the potential role of species separation and anomalous energy dissipation in DT thermonuclear fuels*

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The measurement of strong, self-generated electric fields (~1-10 GVolts/m) in imploding capsules [1], their attribution to polarized (plasma) shock fronts [2], and the identification of plasma-enhanced binary species diffusion from barodiffusion and electrodiffusion [3] have led to a growing interest in the potential role of species separation in inertial-confinement-fusion (ICF) thermonuclear fuels. In particular, the arranged sequence of (4) shocks in a central-hot-spot ICF target may lead to transient species separation of the deuterium (D) and tritium (T) across each shock front as the main DT fuel is traversed. The process of species separation involves interpenetration of each fuel species, resulting in a drift velocity that can lead to resistive-like (or frictional) heating. Estimates of the degree of dissipation energy following four-shock traversal of the main fuel give on the order of 100 Joules, which is sufficient to significantly impact ignition performance margins. A number of anomalies on the National Ignition Facility (NIF) shock-timing database may be consistent with frictional heating of the CH ablator following shock passage. In particular, VISAR data show a large difference on the 1st and 2nd shock merger time within the D_2 fuel compared with modeling, requiring ~43% reduction in simulated laser power to match the observations. A scenario is proposed where the 1st shock deposits an additional ~1 eV per ion in the ablator due to mixed-species shock-front dissipation, leading to an anomalous expansion of ~20 μm before 2nd shock launch ~12 ns later and a subsequent delay in shock merging. Additional shock heating over what is expected in a classical fluid may be consistent with the modified Rankine-Hugoniot jump conditions for a multi-species plasma with self-generated fields [4]. LSP simulations of the coalesced shock in the DT gas of a NIF ignition capsule show a distinct bifurcation of the shock into separate deuterium- and tritium-rich components, thereby altering the conventional (fluid-based) notion of shock morphology.

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[Prefer Oral]

Effects of ion diffusion on fusion burn at the shock flash in inertial-confinement fusion implosions

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Spectra of multiple charged-fusion products from tritium-helium-3 (T^3He) and deuterium-trium-helium-3 (DT^3He) gas-filled capsule implosions with exploding-pusher mode are obtained. For the first time, four simultaneous nuclear products have been observed and used to infer stratification [1] of ions with different electric charge states (Z) and charge-to-mass ratios (Z_i/m_i). In addition, these exploding-pusher implosions warrant that such effects must be resulted from the shock wave front. These experiments are vitally important for verifying and understanding the recent theoretical work by Amendt et al. [2] about plasma mass diffusion across the shock front due to the thermodynamic gradients. While there are a number of diffusion sources, including the conventional concentration diffusion (due to concentration gradient), barodiffusion (due to pressure gradient), electrodiffusion (due to electric field), and thermodiffusion (due to temperature gradient), it is suggested that barodiffusion and electrodiffusion are the dominant sources [3] in these implosions. These experiments provide new physical insight into the effects of the ion diffusion on species stratification in shocked/reshocked hot plasmas and have important implication to the ongoing experiments of National Ignition Campaign (NIC) at the National Ignition Facility (NIF).

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Dependence of the fusion yield on the separation of d and t ions in exploding pusher simulations

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It is shown by means of hybrid particle-in-cell simulations that convergence of the spherical shock wave that propagates through the inner gas of an exploding pusher experiment is accompanied by separation of d and t ions across the shock front. Deuterons run ahead of the tritons and reach the center ~10 ps before the tritons. Decoupling of the d and t ions, in terms of both density and temperature, leads to a degradation of the DT fusion yield. This is accompanied by a modification of the DD/DT and TT/DT fusion yields. This study reveals the necessity of including multiple-species effects in ICF simulations.

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Ion concentration diffusion in ICF implosions

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Optimizing fusion yield in inertial confinement fusion (ICF) experiments requires number densities of the reactants to be equal throughout the fuel assembly. This condition can be easily satisfied during target fabrication. However, dynamical process of implosion gives rise to the inter-ion-species transport, resulting in these species' concentrations being perturbed from their initial values. In particular, classical, baro-, electro- and thermo-diffusive mechanisms of such a transport should be distinguished.

To evaluate associated diffusion coefficients, fluid equations for the individual ion species are first employed. Substantial insight into the relative importance of the baro- and electro-diffusions can then be obtained without invoking a kinetic calculation due to the baro- and electro-diffusion ratios being thermodynamic quantities. On the contrary, thermo-diffusion ratios appearing in front of the ion and electron temperature gradients, as well as the classical diffusion coefficient, are intrinsically non-thermodynamic. To obtain these parameters, kinetic calculation is performed to evaluate electron-ion and ion-ion thermal forces, as well as the ion-ion dynamic friction, respectively. Explicit dependence of the diffusion coefficients on the species' concentrations is found numerically for selected pairs of ion species. Initial implications of these newly obtained results are discussed.

Advanced ablator target designs for shock and hot spot ignition on the National Ignition Facility

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A major concern for direct drive implosions at the NIF scale is the DT-fuel preheating by hot electrons produced by the two plasmon decay instability (TPD). Experiments on OMEGA using thick glass targets [V. Smalyuk et al, Phys. Rev. Lett. 104, 165002 (2010)] showed that glass SiO_2 ablators produced a hard x-ray signal from hot electrons that is 40x lower than in plastic shells for the same laser intensity. These results have stimulated research in new ablator materials with higher Z than plastic CH for direct drive targets. More recent experiments [D. Froula et al, submitted to Plasma Phys. Cont. Fusion] indicate a clear trend between the reduction in hot electron preheat and the atomic number of the ablator. At this time, it is unclear whether the reduction in hot electrons is due to higher linear thresholds or to nonlinear saturation mechanisms.

A set of moderate Z ablators ranging from carbon to silicon has been used to design both hot spot and shock ignition targets at laser energies relevant to the National Ignition Facility. The hydrodynamics of these ablators is studied through single and multimode simulations. Hydro-instabilities exhibit complex behavior in these ablators due to the presence of a double ablation front (thermal and radiative) and a classically unstable interface. The width of the double ablation front grows with Z and the Rayleigh-Taylor instability becomes more localized near the radiative front and the classical interface while it is fully stabilized at the thermal ablation front.

It is shown that ignition target designs with reasonably good hydrodynamic properties using moderate Z ablators are possible for both shock and hot spot ignition. Carbon ablators appears to be the most suitable for high gain targets with ignition margins exceeding even those of current plastic shell designs.

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Relativistic Particle Wakes and Their Impact on Electron Stopping*

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A detailed understanding of electron stopping and scattering in plasmas with variable values for the number of particles within a Debye sphere is still not at hand. Presently, there is some disagreement in the literature[1,2,3] concerning the proper description of these processes. Detailed theoretical models exist for the stopping power of a single relativistic electron in a plasma, including quantum mechanical effects. However, few theories take into account correlation effects, in which the wake produced by an electron modifies the dynamics and stopping power of the electrons that travel behind it. Some have performed simple studies of correlated stopping, but have neglected the dynamics of electrons that travel in the wake, such as their tendency to move in or out of the wake[4,5]. Developing and validating proper descriptions requires studying the processes using first-principle plasma simulations. We are using the particle-in-cell (PIC) codes OSIRIS and QuickPIC to perform these simulations. As a starting point in our study, we examine the wake of a particle passing through a plasma in 3D relativistic electromagnetic simulations using various cell sizes and compare the results with cold plasma theory. We also present some initial stopping power results. The relevance of the work to Fast Ignition is discussed.

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Acceleration and Transport of Electrons Created Using High Intensity Lasers and High Density Targets*

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The spectrum and transport of energetic electrons created at a steep interface by a high intensity laser are investigated using the particle-in-cell code OSIRIS. Our earlier work has shown that in such conditions, accelerated particles are born in a volume within a quarter wavelength of the plasma surface, by a mechanism controlled by the standing wave structure of the laser field. This leads to an inherent divergence even in 1D, due to constraints on the initial and final momentum of accelerated particles. Investigating this regime in 3D, we find an early-time anisotropy with greater divergence in the plane of the laser E field, as expected; as the source evolves and becomes less ideal this effect becomes less pronounced. We will also show the results of 2D PIC simulation of a recent Omega experiment, in which electrons are generated by the Omega EP laser illuminating a gold foil, and then transport through a pre-formed CH plasma.

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Acceleration of relativistic electrons in plasma channels

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Abstract

Acceleration of high energy electrons in underdense plasmas by laser pulses undergoing relativistic self-focusing and channeling has been well documented in experiments and simulations [1]. The physical processes responsible for acceleration in plasma channels in the context of experiments carried out with gas jet targets [1] are also at work in underdense plasmas created at the front of solid targets where they contribute to fast ignition, ion acceleration and positron generation experiments.

We present here detailed study of electron acceleration in plasma channels based on our recently developed scenario [2] of stable relativistic self-focusing, laser pulse channeling, surface wave generation and complex electron dynamics in the electromagnetic and electrostatic fields of the ion channels. By means of 3D PIC simulations we study the interaction of laser pulses having their intensity $I\lambda^2$ in the range $[10^{19}, 10^{20}]$ W/cm^2 μm^2, focused in a plasma of electron density n_0 such that the ratio n_0/n_c lies in the interval $[10^{-3}, 10^{-1}]$, n_c denoting the critical density [1].

The laser front gives rise to the excitation of a surface wave [3], which propagates along the sharp boundaries [4] of the electron free channel created by the laser pulse. The mechanism responsible for the generation of the fast electrons observed in the PIC simulations is then analyzed by means of a test particles code. It is thus found [2] that the fast electrons are generated by the combination of the acceleration by the surface wave and of the betatron process [5]. The maximum electron energy observed in the simulations with $I\lambda^2 = 10^{20}$ W/cm^2 μm^2 and $n_0/n_c = 2\text{x}10^{-2}$ is 350 MeV. Using test particle simulations we study the scaling of the number and energy of accelerated electrons with laser intensity and background plasma density.

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Hot Electron Generation from laser-pre-plasma interactions in cone guided Fast Ignition

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Abstract

Two-dimensional PIC simulations were performed for the cone-in-shell integrated fast ignition experiments on the Omega laser facility [W. Theobald et al., Phys. Plasmas, May 2011]. The initial plasma density profile in the PIC simulations was taken from the hydrodynamic simulations, including the pre-plasma inside the gold cone generated by the pre-pulse. The laser had an intensity of 1×10^{19} W/cm^2 and duration of 10 ps. The hot electrons generation from laser-pre-plasma interactions and the electron transport in under-100n_c plasmas were studied. An artificial drag was applied to hot electrons above 30kev in the >100 n_c region to facilitate the establishment of a return current and allow the simulations to run close to 10ps. The simulation results showed a large mean divergence angle of 68 degree and high absorption rate of 50% for the hot electrons generated. Many low-energy (<300kev) electrons were generated but half of the energy was carried by high-energy (>4Mev) electrons. The electrons transport in the small density region (<100n_c) was ballistic in the early stage. In the late stage of the simulation, all the results were largely independent of polarization.

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Collisional PIC modeling of plasma instabilities

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We will present results of collisional PIC simulations of counter streaming flows where both collisional (resistive) effects and plasma instabilities are important. Details of the numerical difficulties encountered to obtain the correct physics will be described. In particular spurious transverse diffusion has to be controlled to avoid numerical transfer of the very large kinetic energy into thermal energy, while a small continuous resistive heating occurs. Results will be compared with experimental measurements. We will describe how we address similar problems occurring for fast-ignition simulations at much higher energies and densities.

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Hybrid-PIC Simulations of Shock Formation in Laser-Irradiated Plasmas

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Shock generation by hot electron beams (with corresponding energy fluxes ranging from $10^{14}\ W/cm^2$ to $10^{16}\ W/cm^2$) impinging on high density targets ($10^{25}\ 1/cm^3$) is investigated using the hybrid-PIC version of OSIRIS. The hybrid-PIC code uses a fluid model to follow electron transport at high densities. In these simulations an electron cathode is used as a proxy for hot electrons generated in under-dense regions by laser-plasma interactions. This approach enables control over the composition and energy distribution of the hot electrons entering the high density region, which, in turn, allows the direct study of hot electron energy deposition and the corresponding shock structure. Understanding how to harness the hot electrons to enhance shock formation will aid in designing Shock Ignition ICF targets with improved yield. Work Supported by the DOE under a Fusion Science Center through a University of Rochester subcontract No. 415025- G and under DE-FG52-09NA29552.

IMPLICIT VLASOV-FOKKER-PLANCK SIMULATIONS FOR NON-UNIFORMLY LASER-IRRADIATED PLASMAS

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The conduction of energy in over-dense plasmas irradiated by lasers with intensity above 10^{15} W/cm^2 depends on the non-local transport of hot electrons. Therefore, in shock ignition scenarios, for which such high-intensity lasers are required, understanding the connection between the detailed structure of the electron distribution function and the non-local features of the transport is crucial. Vlasov-Fokker-Planck simulations are the most accurate method for studying non-local electron transport, but their applicability has been limited, because—in order to reduce computational cost—they too have employed assumptions on the shape of the distribution function. Using the 2D3P parallel VFP code OSHUN [1], that incorporates the expansion of the electron distribution function to an arbitrary number of terms, we investigate the limitations of the most common VFP approaches. A new implicit algorithm for the electric field in OSHUN will be presented, which enables rapid calculations for timescales in excess of 100ps for solid-density targets, thereby facilitating parameter scans for multi-dimensional problems. These reveal that large temperature non-uniformity and the generation and amplification of magnetic fields in laser-irradiated plasmas limit the accuracy of reduced methods. For example, our preliminary results indicate that the baroclinic magnetic fields are stronger and more concentrated to the surface of the target than what is predicted by the diffusive approximation. At the same time hot electrons penetrate deeper in the target, not just compared to hydrodynamic simulations, but also compared to 1D diffusive simulations [2]. Finally, benchmarks between this code and non-local models used in fluid codes will be presented for test problems. This work is supported by the DOE under Fusion Science Center through a University of Rochester subcontract No. 415025- G and under DE-FG52-09NA29552.

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2D hydrodynamic simulations for the interpretation of the controlling fast electron beam divergence using two laser pulses experiment.

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ABSTRACT

Guiding of a relativistic electron beam in a solid target was demonstrated in an experiment, performed at RAL, using two colinear relativistic intensity, picosecond laser pulses. The first one creates favorable conditions for guiding of the fast electron beam generated by the second one. The effects of intensity ratio, delay, total energy and intrinsic pre-pulse of the two pulses are examined. Thermal and Kα imaging showed reduced emission size, increased peak emission and increased total emission at delays of 4 - 6ps. The experiment was modelled using the 2D radiation hydrodynamics code CHIC included with the MHD and fast electron transport modules. Magnetic fields are generated by the resistive electric field and the cross product of the gradients of the electron density and temperature. The electric field is calculated assuming the total current neutralization. The plasma resistivity was described by the Spitzer formula above 100eV and by an interpolation formula. The fast electron transport is calculated with the reduced kinetic model that accounts for the self-consistent magnetic fields and collisions with plasma electrons and ions. The intensity of Cu-Kα emission was calculated with a post-processor. These results indicate reduced fast electron divergence, increased fast electron current density and increased fast electron current. The enhancements are attributed to the generation of magnetic fields within the target which act to collimate the divergent fast electrons. Such a scheme could be of considerable benefit to fast ignition inertial fusion.

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Magneto-Hydrodynamic Effects in Ablatively-Driven High Energy Density Systems

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Magneto-hydrodynamic effects are of fundamental interest in high energy density physics (HEDP). This includes the onset of hydrodynamic instabilities, current instabilities, and plasma flow instabilities, and their effect on energy coupling and ablative drive at multi-Mbar pressures. Results from ultrafast laser-driven proton radiography experiments for probing high-power, laser-driven ablator dynamics at the Omega EP Laser Facility will be presented. Thin plastic foils are irradiated with 4-kJ, 2.5-ns laser pulses focused to an intensity of ~10^{14} W/cm^2. Generation and evolution of small-scale non-uniformities in and around the driven-target are observed with high spatial and temporal resolution. Comparison of the experimental results with numerical simulations indicates the generation mechanisms for the detected filamentary structures. Meanwhile, self-generated electromagnetic fields are inferred.

Friday, June 29th 2012

Extremely high pressure generation by implosion plasmas with cone-in-shell targets

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Intense laser is now one of the standard tools for generation of ultrahigh pressure. Ablation pressure is a function of laser wavelength and absorbed laser intensity, however, there is a limitation of pressure because the absorption is eliminated due to several kinds of laser-plasma interactions in high intensity regime. We here propose a novel scheme to generate ultra-high pressure by using laser implosion plasma. The highest pressure ever has been created by inertial confinement fusion plasmas, but it is difficult to use as is for compression of matters. For practical use of the pressure, a modified cone-in-shell target was employed.

Experiments were conducted at GEKKO-XII laser facility at ILE, Osaka University. Nine of twelve beams irradiated the cone-in shell targets. The pulse duration was 3.5 ns, and total laser energy was ~ 2 kJ (2ω, λ: 527 nm). The targets were cone (Au)-in-CD shell. In this experiment, since we do not need high-temperature hot spot, we employed small and thick shell for low-adiabat compression. The diameter and thickness of the shell were 350 μm and 20 μm, respectively. The tip of the cone, whose diameter was 100 μm, was aluminum or gold foil with small "hole" (diameter: ~40 μm) inside of the cone in order to measure the shock breakout timing described below. The thickness and depth of the hole were 10 – 20 μm and 5 – 10 μm, respectively.

Self-emission due to shock breakout was measured by an optical streak camera. From difference of shock breakout timing of the stepped tip, shock velocity was directly obtained. We estimated the pressure by the measured shock velocity and an extrapolation of previous EOS measurements. Preliminary analysis suggests that the observed pressure was beyond 10 TPa, which is smaller than the prediction by 2D simulation.

Study on energy loss of energetic electrons in dense plasmas

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Energy loss of energetic electrons in dense plasmas is of great importance in inertial confinement fusion (ICF) study, i.e. the energy deposition process in electron fast ignition, the capsule preheat by LPI electrons in central hot spot ignition, etc. Kinetic description can provide a relatively accurate way to study the energy loss by following the evolution of particle distribution function in phasespaces. Within ICF context, a kinetic model is developed by taking into account both binary collisions and the contribution due to plasma collective process. The relativistic effect of energetic electrons is also included. The resulting collision terms can be explicitly expressed via simple differentiations and quadratures. Numerical code is well developed based on the established kinetic equation, which has been benchmarked. Applications in ICF related energy loss study are presented. Numerical results show the electron range and penetration depth, as well as their dependence on initial kinetic energy. Investigations on the effect of varied initial electron distributions and plasmas condition are also discussed.

Getting Results From Kα Images and Yields Using LSP.*

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Laser-excited hot electrons, with energies exceeding 1 MeV, from the laser plasma interaction initiate a wide variety of phenomena in high energy density physics. There is an ongoing, broad effort to determine the hot electron energy and spatial distribution over a wide range of conditions as well as key figures of merit such as the laser to hot electron energy conversion efficiency. The measurement of Kα images and yields plays a key role in this effort. We present data collected at the LLNL Jupiter Laser facility and the Texas Petawatt Project over a period of four years involving slab targets, buried cone targets, and cone-wire targets at intensities of 10^{19} W/cm^2 or higher. We compare our results to 2D LSP[1] PIC simulations, achieving good agreement over a range of conditions.[2]

We find that, taken directly, Kα images can be a poor measure of the laser excited hot electron spatial distribution because they are time-integrated, leading to measurement of electrons with widely differing histories due to refluxing and laser generated quasi-static fields. The use of large targets with "get-lost-layers" of carbon on the rear of the target help, but do not eliminate the problem because of significant refluxing from the front surface. Comparison to PIC simulations can not only help determine the desired distributions, but new information can be extracted. We have found that the Kα image background, normally subtracted before analysis, can provide a sensitive measure of the location of the laser critical surface, a key measure of the effect of pre-plasma. The background and wings of the image provide sensitive measures of the amount of target refluxing present. We find that successful simulations must realistically model the laser, use full-scale targets (~1 mm extent) and integrate for long times (up to 20 ps). We describe the tradeoffs involved between resolving the laser plasma interaction and treating the required spatial and temporal scales for this work. Finally, we show that, although injection based models remain a valuable approach in PIC simulation, important phenomena are lost unless realistic laser angular distributions are used.

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Mean Fast Electron Energy in Laser-Solid Interactions from 10^{18} to 10^{19} W cm^{-2} Determined from Time Resolved K alpha Emission

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Time resolved measurements of K alpha emission from 20 μm thick copper foils irradiated by ps laser pulses at peak intensities from 10^{18} to 10^{19} W cm^{-2} have been made on the MTW (Multi TeraWatt) laser at the Laboratory for Laser Energetics. The rise times at all intensities were 1 ps, determined by the temporal resolution of the streak camera. The decay times increased with intensity from 1 to 3.5 ps. The decay curves are consistent with fast electrons with a broad distribution of energies passing repeatedly through the targets until they deposit their energy. The results were modelled assuming that fast electrons remained within the target and lost energy to collisions. Excellent agreement was obtained with the measurements. It was found that decay time is proportional to mean energy and is weakly dependent on the precise energy distribution. The mean fast electron energies obtained scale as the square root of the laser intensity and are between 1 to 1.2 MeV at 10^{19} W cm^{-2}.

Interaction of Multiple Laser Beams via Common Ion Waves and Beam Energy Transfer

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In the plasmas of direct-drive inertial confinement fusion (ICF) experiments, laser power is delivered to the target by multiple laser beams, propagating in different directions in the plasma corona. Therefore the possible energy transfer between the beams has a direct influence on the laser power deposition and the target drive, see for example (Ref. 1).

Laser beams in ICF plasmas are randomized in space (through distributed phase plates) and time (through smoothing by spectral dispersion and multiple colors). These randomizations on the one hand suppress the beams' interaction via ion-acoustic waves by detuning the ion-acoustic resonances, and on the other hand generate a broad spatial and temporal spectrum of ion-acoustic–type perturbations by beating electromagnetic waves possibly seeding the beams' interaction.

To study these competing effects, the simulations were based on the non-paraxial model of light propagation.[2] This model allows us to model the nonlinear propagation of laser beams in wide angular domains. Possible interaction via common ion-acoustic waves has been studied. The results of our laser–plasma interaction model on crossed-beam energy transfer (CBET) point to possible improvements in the existing CBET model based on three-wave interactions and used in large-scale simulations of experiments on the OMEGA Laser System.[1]

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2. A. V. Maximov *et al*., Phys. Plasmas **11**, 2994 (2004).

Prefer oral presentation

Hybrid-PIC Simulations of Shock Formation in Laser-Irradiated Plasmas

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Shock generation by hot electron beams (with corresponding energy fluxes ranging from $10^{14}\ W/cm^2$ to $10^{16}\ W/cm^2$) impinging on high density targets ($10^{25}\ 1/cm^3$) is investigated using the hybrid-PIC version of OSIRIS. The hybrid-PIC code uses a fluid model to follow electron transport at high densities. In these simulations an electron cathode is used as a proxy for hot electrons generated in under-dense regions by laser-plasma interactions. This approach enables control over the composition and energy distribution of the hot electrons entering the high density region, which, in turn, allows the direct study of hot electron energy deposition and the corresponding shock structure. Understanding how to harness the hot electrons to enhance shock formation will aid in designing Shock Ignition ICF targets with improved yield. Work Supported by the DOE under a Fusion Science Center through a University of Rochester subcontract No. 415025- G and under DE-FG52-09NA29552.

Particle-in-cell simulations on high-intensity femtosecond laser pulse sub-wavelength structured target interactions

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Interactions of high-intensity femtosecond laser pulse and sub-wavelength structured target were investigated by two-dimensional particle-in-cell simulation. Compared to the plain solid targets, the plain sub-wavelength targets and conical sub-wavelength targets improved the coupling efficiency from laser energy to hot electrons significantly. And the energy of protons accelerated by the sheath field which produced by hot electron cloud at the rear surface of targets were also enhanced. Meanwhile, the collimation of hot electrons and protons were improved.

High charge fast electron acceleration by laser self-focusing effect

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High charge fast electron acceleration by self-focusing effect is proposed. The experiment was hold at SILEX-I laser facility (10J, 31fs, 300TW). When ultrainstense laser interacts with 2.7mm gas jet, tens of nC fast electrons were generated and the charge of electrons increased with square of laser power linearly. Two-dimensional particle-in-cell (PIC) simulations show that high charge electron acceleration is dominant by self-focusing effect, which fits to experimental result very well. This high charge fast electron beam has potential application in bright X-ray source production, which can get high resolution flash radiography of dense matter.