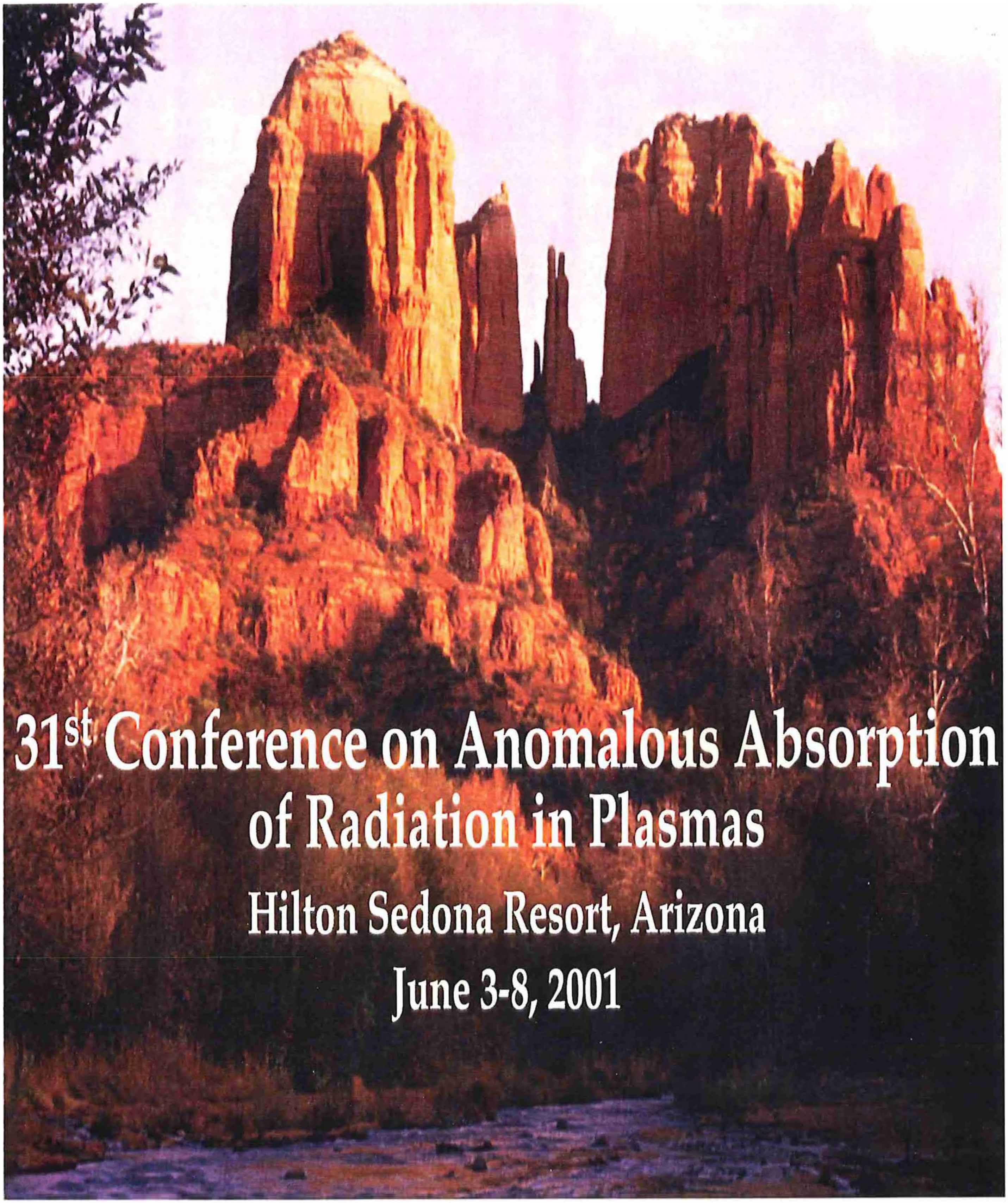
31st Conference on Anomalous Absorption
of Radiation in Plasmas
Hilton Sedona Resort, Arizona
June 3-8, 2001

# 31st Annual
# Anomalous Absorption Conference

## Hilton-Sedona
## Sedona, Arizona
## June 3-8, 2001

## Hosted by Los Alamos National Laboratory


**Conference Organizer: Juan C. Fernández**

**Conference Staff: Sharon Gonzales**
**Leeroy Herrera**
**Marion Hutton**
**Lucy Maestas**

# Program
# 31st Anomalous Absorption Conference

## Monday June 4th, 2001

**8:50 a.m. – 9:00 p.m.** **Welcome**

**9:00 a.m. – 12:20 p.m** **Oral Session 1**

| | Paper No. | 1st Author | Presenter | Title |
|---|---|---|---|---|
| 9:00 a.m. | O1-1 | Williams | Williams | SBS and SRS backscatter in the He/H gasbag experiments |
| 9:20 | O1-2 | Tikhonchuck | Tikhonchuck | Stimulated Brillouin and Raman scattering from a randomized laser beam in preformed plasmas |
| 9:40 | O1-3 | Myatt | Myatt | Large red-shifts of transmitted light and self-induced laser beam incoherence |
| 10:00 | O1-4 | Stevenson | Stevenson | Exploring 2w propagation, backscatter and x-ray and hot electron production on the Helen laser system - an overview |
| 10:20 | O1-5 | Dorr | Dorr | Adaptive mesh refinement in laser-plasma simulation |
| 10:40 | Break | | | |
| 11:00 | O1-6 | Berger | Berger | Stimulated forward and backward Raman scatter |
| 11:20 | O1-7 | Brantov | Rozmus | Electron-ion collisions in a strong laser field and the inverse bremsstrahlung absorption rate |
| 11:40 | O1-8 | Chen | Chen | On stochastic heating by large-amplitude low-frequency waves |
| 12:00 | O1-9 | Hazak | Hazak | Temperature relaxation in two-temperature states of dense electron-ion systems |

**12:20 p.m.** **Lunch**

**7:30 p.m. – 8:30 p.m.** **Review Session 1** **Dr. Charles F "Chick" Keller, "Climate change – an update"**

**8:30 p.m. – 11:00 p.m.** **Poster Session 1**

| | Paper No. | 1st Author | Presenter | Title |
|---|---|---|---|---|
| 8:30 p.m. | P1-1 | Sunahara | Sunahara | Electron thermal conduction in inertial fusion |
| | P1-2 | Simon | Simon | Damping and spatial propagation of oscillations in weakly collisional plasma |
| | P1-3 | Hatchett | Hatchett | New developments in design of cone-focused fast ignition targets |

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|---|---|---|---|
| P1-4 | Tsung | Tsung | PIC simulations of the two-plasmon decay in inhomogeneous plasmas |
| P1-5 | Whitney | Whitney | The calculation of viscosity in multi-ion spherical plasmas |
| P1-6 | Davis | Davis | Intense x-ray emission from a Krypton gas jet on the Helen laser |
| P1-7 | Miller | Miller | Multi-keV x-ray emission from under dense gas targets irradiated with 532 nm and 351 nm laser light |
| P1-8 | Rosen | Rosen | Application of an unpublished Marshak wave solution to an experiment on x-ray transport in a heated foam cylinder |
| P1-9 | Suter | Suter on Helen | Green light laser-plasma interaction experiments |
| P1-10 | Clark | Clark | Regime for a self-ionizing Raman laser pulse compressor |
| P1-11 | Rose | Rose | The weakly damped electron acoustic mode: Who ordered that? |
| P1-12 | Montgomery | Montgomery | Observation of stimulated electron acoustic wave scattering: the case for nonlinear kinetic effects |
| P1-13 | Fernández | Fernández | Scaling of the SRS reflectivity of a single hot spot laser beam with laser intensity |
| P1-14 | Vu | Vu | Kinetic and non-kinetic regimes of SRS nonlinear saturation |
| P1-15 | Focia | Focia | Observation of multiple cascade steps of the Langmuir decay instability in a laser plasma |
| P1-16 | Cobble | Cobble | Cyclic plasma shearing interferometry for temporal characterization of a laser-produced plasma |
| P1-17 | Bauer | Bauer | The Leopard petawatt laser system |
| P1-18 | Bar-Shalom | Bar-Shalom | Non-LTE databases for hydrodynamics simulations of laser-produced plasmas |
| P1-19 | Olson | Olson | Inference of hohlraum temperature, albedo and conversion efficiency via time and spatially resolved x-ray re-emission measurements |
| P1-20 | Olson | Olson | A comparison of shock velocity and x-ray re-emission measurements of radiation temperature in Omega hohlraum experiments |

# Tuesday June 5th, 2001

## 9:00 a.m. – 12:20 p.m. Oral Session 2

| | Paper No. | 1st Author | Presenter | Title |
|---|---|---|---|---|
| 9:00 a.m. | O2-1 | Kirkwood | Kirkwood | Scaling of energy transfer between crossing laser beams with beam intensity and plasma size and density |
| 9:20 | O2-2 | Aglitskiy | Aglitskiy | Direct observation of mass oscillations due to ablative Richtmyer-Meshkov instability and feedout in planar plastic targets |
| 9:20 | O2-3 | Velikovich | Velikovich | Aereal mass oscillations in laser-driven plastic targets due to ablative Richtmyer-Meshkov instability and feedout: theory and simulations |
| 10:00 | O2-4 | Shiraga | Shiraga | Measurements of growth rates in laser-driven Rayleigh-Taylor instability |
| 10:20 | O2-5 | Barnes | Barnes | Further adventures in convergent mix |
| 10:40 | Break | | | |
| 11:00 | O2-6 | Batha | Batha | Observation of mix in a compressible plasma in a convergent cylindrical geometry |
| 11:20 | O2-7 | Lanier | Lanier | Feasibility of fluorescence-based imaging for turbulence and mix studies in compressible, convergent implosions |
| 11:40 | O2-8 | Glebov | Glebov | Current status of tertiary neutron diagnostic by carbon activation |
| 12:00N | O2-9 | Swift | Swift | Laser-generated shocks for dynamic material strength and phase studies for ICF |
| **12:20 p.m.** | **Lunch** | 6:30 dinner | | |

**7:30 p.m. – 8:30 p.m.** **Review Session 2** **Dr. William Zajc, "Quark-gluon plasmas: initial results from RHIC"**

**8:30 p.m. – 11:00 p.m.** **Poster Session 2**

| Paper No. | 1st Author | Presenter | Title |
|---|---|---|---|
| P2-1 | Kovalev | Tikhonchuk | Exact kinetic solutions for non-isothermal plasma expansion |
| P2-2 | Riconda | Tikhonchuk | Instability of a driven ion acoustic wave in a fluid regime |
| P2-3 | Jones | Kruer | The 0.53 um laser option for advanced Applications |

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|---|---|---|---|
| P2-4 | Ortelli | Kruer | Plasma instability channeling for advanced applications of high power lasers |
| P2-5 | Lours | Lours | Cryogenic gasbag experiments on Nova |
| P2-6 | Larroche | Larroche | Fokker-Planck simulation of DT capsule implosions and hot-spot formation for ICF |
| P2-7 | Casanova | Casanova | Targets for laser-plasma interaction studies on the LIL facility |
| P2-8 | Bonnaud | Riazuelo | Influence of filamentation and optical smoothing techniques on speckle statistics in the FCI context |
| P2-9 | Depierreux | Depierreux | Design of a Thomson scattering probe for the LIL facility |
| P2-10 | Still | Still | Comparing partial beam simulations to whole beam simulations with PF3D |
| P2-11 | Berger | Berger | Modeling stimulated Raman backscatter |
| P2-12 | Schmitt | Schmitt | Direct drive pellet designs for the National Ignition Facility |
| P2-13 | Obenschain | Obenschain | Experimental studies of the effects of thin gold layers on imprinting of laser nonuniformity onto plastic targets |
| P2-14 | Colombant | Colombant | Modeling of KrF laser interaction with thin gold layers over plastic targets |
| P2-15 | Serlin | Serlin | New/old diagnostics: streak camera coupled with the high resolution x-ray imager |
| P2-16 | Aglitskiy | Aglitskiy | Direct observation of feedout-related aereal mass oscillations in planar plastic targets |
| P2-17 | Karasik | Karasik | Direct observation of areal mass oscillations due to ablative Richtmeyer-Meshkov instability in planar targets |
| P2-18 | Gardner | Gardner | Numerical simulation of ablative Richtmeyer-Meshkov instability and feedout experiments on the Nike laser facility |
| P2-19 | Weaver | Weaver | Absolutely calibrated, time resolved measurements of soft x-ray emission at the Nike laser facility |
| P2-20 | Bates | Bates | Influence of nonlinear heat conduction on shock Waves in spherical explosions |
| P2-21 | Afeyan | Afeyan | WRMR Analysis: Wigner function representations of multi-resolution analysis and its applications in plasma physics |
| P2-22 | Swift | Swift | Dynamic material property measurements with laser-launched flyer plates |

## Wednesday June 6th, 2001

## 1:30 p.m. – 4:10 p.m. Oral Session 3

| | Paper No. | 1st Author | Presenter | Title |
|---|---|---|---|---|
| 1:30 p.m. | O3-1 | Malkin | Fisch | Compression solutions for backward Raman amplification |
| 1:50 | O3-2 | Kodama | Kodama | Studies of high-energy particle generation and energy transport in ultra-intense laser-plasma interactions |
| 2:10 | O3-3 | Kodama | Kodama | Recent activities on fast ignition research at Osaka University – enforced heating of highly compressed plasmas |
| 2:30 | O3-4 | Ren | Ren | Laser self-focusing in a magnetized plasma |
| 2:50 | O3-5 | Naumova | Naumova | Formation of electromagnetic post-solitons in plasmas |
| 3:10 PM | Break | | | |
| 3:30 | O3-6 | Kingham | Kingham | A new mechanism for magnetic-field generation in collisional plasmas |
| 3:50 | O3-7 | Faenov | Faenov | X-ray radiation properties of different clusters under high-intensive fs laser-interaction |
| 4:10 | O3-8 | Sokolov | Sokolov | Harmonics generation in super-bright laser pulse propagating through a capillary |

**4:30 p.m. – 5:30 p.m.** **Business Meeting**

# Thursday June 7th, 2001

## 9:00 a.m. – 12:20 p.m. Oral Session 4

| | Paper No. | 1st Author | Presenter | Title |
|---|---|---|---|---|
| 9:00 a.m. | O4-1 | Craxton | Craxton | Design of long-scale-length plasmas for interaction physics experiments on Omega |
| 9:20 | O4-2 | Seka | Seka | Multibeam SBS interaction experiments in Omega long-scale-length plasmas |
| 9:40 | O4-3 | Short | Short | Theoretical interpretation of SBS observations in Omega long-scale-length plasmas |
| 10:00 | O4-4 | Stoeckl | Stoeckl | Measurements on the two-plasmon decay instability on Omega |
| 10:20 | O4-5 | Afeyan | Afeyan | Optical mixing controlled stimulated scattering instabilities in Beryllium targets: the weak ion wave damping regime |
| 10:40 | Break | | | |
| 11:00 | O4-6 | Depierreux | Depierreux | Influence of the Langmuir decay instability on the saturation of stimulated Raman scattering |
| 11:20 | O4-7 | Montgomery | Montgomery | Recent Trident single hot spot experiments: evidence for kinetic effects and observation of LDI cascade |
| 11:40 | O4-8 | Rose | Rose | Damping rate for weakly perturbed large amplitude BGK modes |
| 12:00N | O4-9 | Hinkel | Hinkel | Laser-plasma interactions in reduced-scale halfraums |

**12:20 p.m. Lunch**

~~**7:30 p.m. – 8:30 p.m. Review Session 4 Confirmation Pending**~~ 6:30 – 8:30 Dinner → Cancel

**~~8:30~~ p.m. – 11:00 p.m. Poster Session 4**

| | 1st Author | Presenter | Title |
|---|---|---|---|
| P4-1 | Langdon | Langdon | Laser-plasma interactions in overlapping laser beams |
| P4-2 | Batishchev | Capjack | Heat transport and electron distribution function in laser produced plasmas heated by localized hot spots |
| P4-3 | Maximov | Rozmus | Nonlinear evolution of laser filaments in plasmas |
| P4-4 | Valeo | Valeo | A kinetic delta-f model of plasma and Acoustic waves which includes an evolving background distribution - implementation in two spatial dimensions |

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|---|---|---|---|
| P4-5 | Brunner | Brunner | Velocity distribution functions in laser hot spots |
| P4-6 | Stepanov | Faenov | Direct spectroscopic observation of ion acceleration in CO2 laser-produced plasmas |
| P4-7 | Demchenko | Faenov | About a role of resonant absorption of laser radiation at generation of fast ions in CO2 laser-produced plasmas |
| P4-8 | Ren | Ren | Braiding of two spiraling laser beams due to plasma wave wakes |
| P4-9 | Mori | Mori | A variational approach to coupling between forward Brillouin scattering and self-focusing |
| P4-10 | Silva | Mori | Collisional effects on intense electron beam propagation in plasmas andtheir relevance to the fast ignitor concept |
| P4-11 | Gordon | Gordon | Simulations of pulse compression and amplification in a plasma |
| P4-12 | Faenov | Pikuz | Portable, tunable, high-luminosity spherical crystal spectrometers with x-ray CCD or MCP for high-resolution x-ray spectromicroscopy of fs laser-produced plasmas |
| P4-13 | Pollack | Pollack | Direct experimental determination of spatial temperature, density and mix for LTE implosions |
| P4-14 | Langer | Langer | Line emission as a function of surface roughness in 2D and 3D |
| P4-15 | Christensen | Christensen | Direct numerical calculation of x-ray and neutron imaging using apertures |
| P4-16 | Keiter | Keiter | Observation of a hydrodynamically driven, radiative-precursor shock |
| P4-17 | Drake | Keiter | Raleigh Taylor growth exponents at decelerating Interfaces |
| P4-18 | Mason | Mason | A 3D ray-trace model for RAGE |
| P4-19 | Pollaine | Pollaine | Modeling laser material strength experiments |
| P4-20 | Watt | Watt | Experimental studies of ICF double shell implosions with nearly 1D behavior cylindrical and tetrahedral hohlraums |

# Friday June 8th, 2001

## 9:00 a.m. – 12:20 p.m. Oral Session 5

| | Paper No. | 1st Author | Presenter | Title |
|---|---|---|---|---|
| 9:00 a.m. | O5-1 | Delettrez | Delettrez | Precision one-dimensional LILAC simulations of CH-shell implosions on the Omega laser |
| 9:20 | O5-2 | Regan | Regan | Core-mix measurements of direct-drive implosions on Omega |
| 9:40 | O5-3 | Epstein | Epstein | One-dimensional simulation of the effects of unstable mix on neutron and charged-particle yield from laser-driven implosion experiments |
| 10:00 | O5-4 | Suter | Suter | Green Light Targets for NIF |
| 10:20 | Break | | | |
| 10:40 | O5-5 | Amendt | Amendt | Indirectly-driven noncryogenic double-shell ignition target designs for the National Ignition Facility |
| 11:00 | O5-6 | Goncharov | Goncharov | Hydrodynamic stability of moderate to high gain direct-drive targets for the NIF |
| **11:20** | | **Conclusion** | | |
| **11:30** | | **Final lunch** | | |

# 31st Annual
# Anomalous Absorption Conference

## Monday, June 4, 2001

| | | |
|---|---|---|
| 8:50 a.m. | **Welcome** | |
| 9:00 a.m. – 12:20 p.m. | **Oral Session 1** | Bedros Afeyan |
| 12:20 p.m. | **Lunch** | 6:30 Dinner |
| 7:30 p.m. – 8:30 p.m. | **Review Session 1, Invited Talk:**<br>**Dr. Charles "Chick" Keller,**<br>**"Climate change - an update"** | |
| 8:30 p.m. – 11:00 p.m. | **Poster Session 1** | |

# SBS and SRS backscatter in the He/H gasbag experiments.

E. A. Williams, J. D. Moody, L. Lours(1), S. H. Glenzer, R. L. Berger, A. B. Langdon and C. H. Still.

*University of California, Lawrence Livermore National Laboratory, P. O. Box 808, Livermore CA 94550 and (1) CEA/DIF, BP 12, 91680 Bruyeres-le-Chatel, France*

Cryogenic gasbags filled with various mixtures of helium, hydrogen and neon were illuminated with five 351nm heater beams of the Nova laser, creating a ~1mm scale low density (~0.08nc) plasma approximating the interior conditions of a NIF hohlraum. Changing the hydrogen fraction of the gas mixture varied the ion acoustic damping, while the addition of neon increased the laser absorption allowing access to higher electron temperatures.

A sixth 2ns square 351nm laser pulse was delayed by 0.5ns and used as a interaction probe. Measurements were made on the transmitted and backscattered probe light. Typically SBS backscatter was observed early in the interaction pulse, followed by SRS which peaked after the heaters turned off.

Analysis with NEWLIP shows that this behavior was consistent with the linear instability gains inferred from FCI-2 simulations of the plasma conditions. SBS decreased in time because of the increase in Ti/Te (increasing the ion Landau damping of the ion acoustic waves), while SRS peaked late because the cooler Te's gave less electron Landau damping of the plasma waves.

We undertake a series of 3D fluid simulations of the SBS and SRS backscatter, to see if a consistent picture of the saturation levels emerges that explains its time and material dependence.

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

O1-2



# Modeling of stimulated Brillouin and Raman scattering from a randomized laser beam in preformed plasmas

Vladimir

V. T. Tikhonchuk[1*], J. Fuchs[2], C. Labaune[2], S. Depierreux[2], S. Hüller[3], and H. A. Baldis[4]

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[2]Laboratoire pour l'Utilisation des Lasers Intenses, École Polytechnique, 91128 Palaiseau Cedex, France
[3]Centre de Physique Théorique, École Polytechnique, 91128 Palaiseau Cedex, France
[4]Institute for Laser Science and Applications, Lawrence Livermore National Laboratory, Livermore, CA 94550

A model for stimulated Brillouin (SBS) and Raman (SRS) backscattering of a spatially smoothed laser beam interacting with a collisional, inhomogeneous, expanding plasma is presented. It is based on the independent hot spots description[1]. Self-focusing is taken into account in the computation of the speckle intensity profile and reflectivities. Two additions have been made to previous similar theories[2,3]: (i) the thermal effects are retained along with the ponderomotive force for what concerns speckle self-focusing, and (ii) SRS (convective and absolute) is accounted for in calculations of the speckle reflectivity. The model is benchmarked against recent laser-plasma experiments at LULI[4] with well-characterized interaction conditions. A good agreement is found between the experimental SBS levels and the model calculations using the measured plasma parameters. This agreement applies for two types of beam smoothing techniques, random phase plates and polarization smoothing, various plasma densities and laser energies. Self-focusing itself, and thermal effects in it, play both a fundamental role in defining the level of plasma backscattering. The absolute Raman instability in speckles dominates the SRS response. The model predictions for the SRS reflectivity are less satisfactory, although they demonstrate the same trends as the experimental data. It follows from model calculations and experimental data that the polarization smoothing technique provides an efficient method of control of parametric instabilities allowing a reduction of several times in the level of SBS and SRS reflectivities.
This work was partially performed under the auspices of the U. S.Department of Energy by University of California Lawrence Livermore National Laboratory, through the Institute for Laser Science and Applications, under contract No. W-7405-Eng-48.

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[1] H. A. Rose and D. F. DuBois, Phys. Rev. Lett. **72**, 2883 (1994).
[2] V. T. Tikhonchuk, Ph. Mounaix, and D. Pesme, Phys. Plasmas 4, 2658 (1997).
[3] V. T. Tikhonchuk, S. Hüller, and Ph. Mounaix, Phys. Plasmas 4, 4369 (1997).
[4] J. Fuchs *et al.*, Phys. Plasmas **7**, 4659 (2000).

# Large red-shifts of transmitted light and self-induced laser beam incoherence

J. Myatt[1], D. Pesme[2], V. T. Tikhonchuk[3*], A. Maximov[1], and W. Rozmus[1]

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Previously, two-dimensional hydrodynamic simulations of the interaction of an RPP laser beam with an expanding collisional plasma have demonstrated a close similarity in the spectra of the transmitted light in comparison with data from f/6 RPP LULI experiments[1]. In both cases the transmitted light is strongly red-shifted with $\delta\omega \sim 2k_0c_s$. We briefly review these simulations, and point out that agreement can be found only if we include the thermal contribution to self-focusing due to the finite electron collisionality in these dense $n_e/n_c \sim 0.3$, $T_e \sim 0.6\,\mathrm{keV}$, $Z = 5.3$ (CH) plasmas.

One usually considers that self-induced laser beam incoherence (LBI) is a result of forward SBS. A simple explanation of the experiment and simulation in terms of classical forward SBS is not possible here, since within 20° from the forward direction, for example, the shift would be inadequate $\delta\omega = 2k_0c_s\sin(20^\circ/2) \sim 0.35\,k_0c_s$. This questions our basic understanding of self-induced LBI.

We will demonstrate here that, in the simulations, the shift arises from the combination of two effects. In the region nearest the laser beam, before the maximum in density of the expanding target is reached, strong self-focusing of speckles takes place. The time dependent phase modulation due to the nonlinear evolution of self-focused filaments leads to a large red-shift of the trapped light $\delta\omega \sim k_0c_s$. Near the density maximum, instability of the filament sets in and the filaments are destroyed. The light leaving this region is a broad mixture of unshifted and red shifted light. Further red-shifting and angular spreading of both components then occurs through classical FSBS. No strongly driven SBS is seen.

A proposal is made in which these ideas may be tested using experimental Thomson scattering data from long-wavelength fluctuations, and predictions based on the simulations are presented. The effect of the LBI on backward SBS will also be discussed.

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[1] J. Fuchs, C. Labaune, S. Depierreux, A. Michard, and H. A. Baldis, Phys. Rev. Lett., 86, xxxx (2000); C. Labaune *et al.* C. R. Acad. Sci. Paris, t 1, Série IV, p. 705-718, 2000.

Abstract for 31st Anomalous Absorption Conference
June 3-8 2001
Sedona, AZ

# Exploring 2ω Propagation, Backscatter and X-Ray and Hot Electron Production on the HELEN Laser System - An Overview

M. Stevenson, K Oades, G Slark
Atomic Weapons Establishment Plc, Aldermaston, U.K

L. Suter, C Back, M. Miller, P. Young
Lawrence Livermore National Laboratory, CA

J Grun
Naval Research Laboratory, Washington, DC

J Davis
Alme & Associates, Alexandria, VA

An extensive, collaborative experimental program to examine many of the properties associated with the use of second harmonic light to drive gaseous targets has recently been undertaken at the newly reconfigured multipass HELEN laser at AWE.

The experimental program comprised such diverse elements as gasbags, gas filled containers, gas jets and exploding foils and was diagnosed by an extensive suite of optical and x-ray instrumentation including streaked SRS and SBS spectra and X ray diode measurements.

This paper is intended as an overview to illustrate the wide ranging nature of the experimental program as well as indicating some of the results achieved, many of the topics mentioned above will be discussed in much greater detail during other conference sessions.

Some computational analysis in particular of x-ray production from gasbags will be discussed and comparison with experimental data shown

Please schedule early as this is an overview to other presentations
M. Stevenson AWE plc (Tel +44 118 982 5704, e-mail mark.stevenson@awe.co.uk)

# Adaptive Mesh Refinement in Laser Plasma Simulation

Milo R. Dorr, F. Xabier Garaizar and Jeffrey A. F. Hittinger

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We discuss recent progress in the development of adaptive mesh refinment (AMR) algorithms for the simulation of laser plasma interaction (LPI). The use of AMR is motivated by the desire to simulate problems that are hydrodynamically large, where the simulation domain is substantially larger than more localized regions in which the majority of LPI occurs. The ability to locally adapt the computational grid enables the use of fine grids only in regions where high resolution is needed. Computational efficiency is therefore enhanced by reducing execution time and memory requirements.

In our model, the plasma motion is described by a system of fluid equations expressing conservation of mass, momentum and total energy. This system is discretized using a high-order Godunov method. The forward light propagation is described using a paraxial model that is discretized using a finite difference algorithm. We employ a block-structured AMR approach in which the computational domain consists of a hierarchy of refinement levels, each of which is a disjoint union of rectangular patches. The integration of the coupled plasma fluid and light systems is accomplished through the coordinated integration of the respective models on each refinement level with periodic synchronization across levels. The location of the refined grids changes dynamically during the calculation based on user-prescribed criteria on the plasma and/or light variables. Parallel processing is exploited by distributing the grid patches on each refinement level across processors.

In this talk we will discuss the algorithmic impact of AMR on LPI simulation and identify areas for future research to include the additional physics necessary to address an expanded range of problems. We will also present some simulation results obtained on various test problems.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

# Stimulated forward and backward Raman scatter

**Author: R. L. Berger, LLNL**

Stimulated Raman forward scatter in long-pulse, nonrelativistic laser illumination of plasma is a frail relative of the lurking hulk that humbled Shiva and portends doom for NIF. However, in the hot plasma expected in NIF hohlraums, the Popeye and Olive are predicted to have their day because of the strong Landau damping of the Langmuir wave associated with backscatter and the weak Landau damping of Langmuir wave associated with backscatter†. Here, we look at the evolution of forward Raman in multi-dimensions with speckled laser beams.

† H. X. Vu, D. F. DuBois, and B. Bezzerides, to be published in PRL 2001

Email: berger5@llnl.gov

Oral

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

# Electron-ion collisions in a rong laser field and the inverse bremsstrahl ng absorption rate

A. Brantov[1,2], V. Yu. Bychenkov[2], W. Rozmus[1], R. Sydora[1], and C. E. Capjack[3]

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A description of electron-ion (e-i) collisions in the presence of a strong oscillatory electric field has been an essential part of almost every laser plasma interaction model. Collisional absorption and inverse bremsstrahlung (IB) heating and transport processes rely on a correct expression for the e-i collision frequency. Advances in laser technology, particularly related to generation of ultra short laser pulses and progress in inertial confinement fusion studies have challenged our understanding of collisional processes over a wide range of conditions and plasma parameters.

This talk is partly motivated by recent studies [1] of the IB heating rates which are affected by the group of electrons at initial drift velocities comparable to the oscillatory velocity in a laser field. These electrons follow complicated trajectories and repeatedly scatter on ions producing large angle deflection from their original paths. By performing numerical, test particle calculations we indeed observed such particles. However, we have found that their effect on the IB heating rate is statistically insignificant when the averaging is performed with respect to an equilibrium ensemble of electrons. For strongly anisotropic electron distribution functions [2], which are observed in photoionized gases by high power short laser pulses, the changes in the IB heating rates could be dramatic as compared to predictions of scattering theories based on the Born approximation.

We have also examined several well known theoretical expressions [3,4,5] for the IB heating rates and compared them with numerical test particle calculations. This comparison demonstrated remarkable agreement between different approximations at strong laser fields and sensitive dependence on cut-off parameters at low laser intensities.

[1] G.M. Fraiman, V.A.Mironov and A.A. Balakin, Phys. Rev. Lett. **82**, 319 (1999).

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# On Stochastic Heating by Large-Amplitude Low-Frequency Waves*

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Abstract

We show, by both numerical Poincare plots and analytical consideration, that charged particles confined by a uniform magnetic field can be efficiently heated by large-amplitude waves with frequencies at small fractions of the corresponding cyclotron frequency. The waves can be either electrostatic waves propagating perpendicularly to the confining magnetic field or obliquely propagating shear Alfvén waves. Physically, this heating mechanism involves nonlinear resonances between the periodic guiding-center motion and the cyclotron motion. We note that, since the present shear Alfvén wave heating mechanism preferentially heats charged particles in the perpendicular direction and favors heavier ions, it may be an interesting candidate for the solar corona heating.

*Work supported by DOE and NSF Grants.
†PPPL, Princeton, NJ.

# Temperature relaxation in two-temperature states of dense electron-ion systems

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The theory of relaxation towards thermodynamic equilibrium in two-temperature plasmas was originally developed by Landau[1] and Spitzer[2]. The result was an explicit simple formula which was obtained by summing the energy loss of electrons, via coulomb collisions, using the Fokker-Planck (or Landau) kinetic equation. This approach applies only to ideal (weakly coupled) plasmas for which thermal energy of the particle exceeds by far the potential energy. In principle it does not apply to shocks in metals and liquids and to states generated by ultra-short pulse lasers, in which density is high and potential energy dominates over thermal kinetic energy.

In the present work we will show that for weak electron-ion but *arbitrarily strong ion-ion coupling*, the formula for the rate of energy relaxation may be obtained using elementary considerations combined with the fluctuation-dissipation theorem. The summation over all mode frequencies required by the formula is obtained analytically by applying the f-sum rule. Surprisingly, the rate of temperature relaxation does not depend on the details of the ionic spectrum of excitations $S^{II}(\vec{k},\omega)$ and depends only on the low frequency ($\omega \sim 0$)properties of the electronic spectrum of fluctuations, $S^{ee}(\vec{k},\omega)$. The physical explanation of this feature is that in the relevant range of $\omega$ the spectrum of fluctuations of electron density is independent of $\omega$ thus the overlap integral of the electron-ion spectra is proportional to the total energy in the ionic spectrum of fluctuations, which by the f-sum rule depends only on the ion density. This means that, in spite of the independence on ion spectrum, the formula already includes relaxation by interaction between electrons and all ion (collective and single particle) modes. The well known Landau-Spitzer [1],[2] is recovered, with minor modifications, when the electronic response function near zero frequency is replaced by its random phase approximation with a local field correction. This shows that the Landau theory which was originally derived for ideal plasmas, is in fact more general and applies, with minor modifications, also to systems, with strong ion-ion coupling.

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**Review Session 1**

**Monday, June 4, 2001**

**7:30 - 8:30 p.m.**

# Climate change: an update


## Charles F. Keller

Director of the Institute of Geophysics and Planetary Physics, Los Alamos National Laboratory, Los Alamos, NM 87544


The Intergovernmental Panel on Climate Change (IPCC) has just issued its Third Assessment Report (TAR). Bottom line--despite continuing uncertainty in many areas, scientists are more certain that humans are causing significant warming due to emission to the atmosphere of greenhouse gases. This talk will report on the latest advances in understanding put in the perspective of what we still don't know and are uncertain about. The talk will touch on some of these: Continuing inadequate understanding of the extent and effects of aerosols as both warming and cooling agents in the atmosphere, forcings due to increases in water vapor and clouds, and disagreement between surface and satellite temperature measurements and how large the role of changes in solar activity are.

## Poster Session 1

## Monday, June 4, 2001

## 8:30 – 11:00 p.m.

# Electron Thermal Conduction in Inertial Confinement Fusion

A. Sunahara, J. A. Delettrez, R. W. Short and S. Skupsky

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Electron thermal conduction in laser-produced plasmas, especially in inertial confinement fusion, has been investigated. Two results are presented: (1) electron thermal conduction by the Fokker-Planck (FP) treatment, which includes nonlocal effects, and (2) theoretical analysis and extension of the flux-limited Spitzer-Härm model to include the time development of the anisotropic part of the electron velocity distribution function $f(v)$.

(1) When the electron mean free path is longer than the temperature-gradient scale length, $f(v)$ deviates considerably from the Maxwell distribution function, which is isotropic and depends only on the local density and temperature. In such cases, the Fokker-Planck treatment based on kinetics should be applied. In our Fokker-Planck approach, we expand $f(v)$ by Legendre polynomials and retain $\lambda = 0,1$, and 2; $f_0(v)$ is the isotropic part. Using the calculated nonlocal $f(v)$, we investigate the effects of the nonlocality on ICF implosion by combining the FP code with the hydrodynamic code *LILAC*. The results will be presented in detail.

(2) The flux-limiting parameter in the flux-limited Spitzer-Härm model, which is widely used in simulation of ICF, is empirical, and obtained from comparison with experimental data. We extend the flux-limited Spitzer-Härm model by including the time development of the anisotropic part of $f(v)$. The results show a physical limit to the flux limiter and also a velocity dependence of the thermal flux different from that in the original Spitzer-Härm model. We will compare our results with those of earlier work.

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

Prefere Poster presentation

# Damping and Spatial Propagation of Oscillations in Weakly Collisional Plasma

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Since Landau damping depends on the fine details of the distribution function near the phase velocity of a wave. The effect of including small collisions in otherwise collisionless plasma theory caused concern. This was presumably settled by Lenard and Bernstein[1] (LB) long ago. A similar concern arose about the phenomena of plasma echoes since this too depends on fine details of the electron distribution at velocities close to $\omega_a/k$, where $\omega_a$ is a fixed antenna frequency, and $k$ is set by the antenna structure. Su and Oberman[2] (SO) considered this and concluded that there was a resulting decay of the echo signal as $\exp(-\beta x^3/v^5)$, where $\beta$ is proportional to the electron collision rate. Recently, Ng *et al.*[3] (NG) questioned the validity of SO (and implicitly of LB) and suggested that SO improperly expanded about the Van Kampen continuum. All this was motivated by an experiment by Skiff *et al.*[4] (Skiff) that directly measured the ion distribution function associated with ion sound waves downstream from an antenna. The measurements did not seem to agree with their LB-like analysis.

We have reexamined the NG–Skiff analysis and show that the SO result is correct. In doing so, we also obtain a new form of the LB dispersion relation, in terms of the incomplete gamma function. This is much simpler than the result in LB and allows rapid calculation of the decay rates. We also show that the NG–Skiff analysis is inadequate for calculating the downstream decay from an antenna. This must be done either by a boundary-layer method like that of SO (but for the ion sound case) or by numerically inverting a new expression for the transformed distribution function, which we have derived in a compact and convenient form. To our knowledge, this has not yet been done. For this reason, it is premature to conclude that there is any discrepancy between experiment and the theory of oscillations in weakly collisional plasma.

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

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Request Poster Session

UCRL-JC-142615-Abs-Rev-1

# New Developments in Design of Cone-Focussed Fast Ignition Targets

S. Hatchett, M. Tabak, R. Turner

*LLNL*

R. Stephens,

*GA*

In the "cone-focussed" concept for FI, the spherical capsule has a conical shell of dense material penetrating through one side to near capsule center. The implosion proceeds as usual, the cone holding open a clear path for the high intensity laser so that its energy can be deposited within ~100 $\mu$m or less of the high density core. 2-D simulations, by us, of implosion, ignition, and burn exploring this concept and recent experiments at ILE-Osaka [Kodama *et al, Bull.Am.Phys.Soc.*, **45**, 160, 2000] show considerable promise for the idea.

We report continuing efforts to develop the concept. We test optimizations such as asymmetric implosion drive and asymmetric capsule design to push the imploded core closer to the cone tip and asymmetric ignition to reduce the energy requirement. We explore whether enhanced mix can produce a higher average density core and whether the initial presence of a layer of DT ice on the cone will degrade the implosion performance.

We report designs for an upcoming set of cone-focussed implosion experiments on Omega — testing how the cone "perturbs" the implosion.

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

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31st Annual Anomalous Absorption Conference
Hilton Sedona Resort, Sedona, Arizona

# PIC Simulations of the Two-Plasmon Decay Instability in Inhomogeneous Plasmas

F. S. Tsung[1], B. B. Afeyan[2], W. B. Mori[1]

[1]Department of Physics & Astronomy, University of California in Los Angeles
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We study the two-plasmon decay (TPD) instability in inhomogeneous plasmas with finite lateral width Gaussian and uniform beams using PIC simulations. Our aim is to understand the nonlinear evolution of TPD in such plasmas with and without ion inertia using lower intensities and longer scale lengths than in earlier PIC simulations (Langdon, Lasinski, and Kruer, Phys.Rev.Lett. **43**, 133 (1979)) and using finite width pulses. There are three major saturation mechanisms identified in the literature, the relative relevance of which we wish to explore. The first involves wave-particle interactions and hot tail formation and dominates when ions are immobile. The second is the Langmuir decay instability and cascading sequences of plasmons decaying into secondary plasmons and ion acoustic waves. The third is profile modification and periodic auto-extinction of the TPD instability by density gradient steepening and subsequent relaxation and recurrence of this cycle. We have conducted simulations with successively higher laser intensities for fixed electron temperature, density scale length, and laser wavelength to observe the transition from linear behavior to nonlinear phenomena. Our results show that linear theory predictions (Afeyan et al, Physics of Plasmas, **4**, 3827. (1997)) are remarkably accurate for laser intensities considerably above threshold when ions are immobile. The mode structure and velocity space evolution of the plasma waves at higher intensities still shed light on the energy of hot electrons generated through the nonlinear stages of TPD.

This work was supported by a grant from LLNL and DoE Grant number DE-FG03-98DP00211. The work of BBA was supported by NRL and DoE Grant number DE-FG03-99DO00278.

Prefer Poster Session

# The Calculation of Viscosity in Multi-ion Spherical Plasmas

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Generally, artificial viscosity is used in computer codes to minimize the number of zones needed to model strongly driven hydrodynamic flows in which shock fronts and/or steep gradients in temperature and density can form. It acts as the means to model the shock heating of electrons and ions in a plasma. However, its form has been determined under the assumption that only the viscosity from one ion specie is active in the plasma. In a previous talk, however, it was shown that as a plasma ionizes, the real (classical) electron viscosity can greatly exceed real ion viscosity under conditions where the ion temperature does not greatly exceed the electron temperature. In this talk, these ideas are generalized to multi-ion plasmas. The viscosity calculation, in this case, is complicated by the wider range of mass and temperature differences, on which the viscosity coefficients depend, that are now possible between different ion species. The derivation of the viscosity coefficients for multi-ion, spherically symmetric plasmas is described, their behavior as a function of mass and ionization state ratios is illustrated, and their relevance to shock structure calculations and artificial viscosity heating is discussed.

* Berkeley Scholars, Inc., Springfield VA, 22150
Work supported by Sandia National Laboratories and DTRA

# Intense X-ray Emission from a Krypton Gas Jet on the HELEN Laser

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Naval Research Laboratory, Washington, D.C.

Christina Back, Michael Miller, Laurance Suter
Lawrence Livermore National Laboratory, CA

Kevin Oades, Gary Slark, Mark Stevenson, Dave Lavender
Atomic Weapons Establishment Plc, Aldermaston, U.K

LCDR Greg Cord
Defense Special Weapons Agency, Alexandria, VA

Jean-Pierre Morreeuw, B. D. Dubroca
Commissariate B l'Energie Atomique, France

We have developed a pulsed supersonic gas jet to produce high-density krypton gas for studies of laser interactions with underdense plasmas. We have observed 14% conversion efficiencies of incident laser energy to krypton L-shell radiation between 1.8-2.7 keV. The jet demonstrated high reproducibility and has the advantage of needing no laser entrance windows and producing no debris. These advantages may be valuable for development of intense x-ray sources for materials testing and backlighters.

One arm of the Atomic Weapons Establishment=s HELEN laser (532 nm wavelength) was focused 3mm from the exit of the jet nozzle onto the supersonic gas plume using a 500-micron RPP. The peak laser intensity was about $2x10^{14}$ W/cm$^2$ at the typical laser power of 0.4 TW with a 1 ns square pulse. We measured the total x-ray fluence, the spectral characteristics, the time structure of emission and time resolved spatial characteristics of the laser produced plasma. Diagnostics included a crystal spectrometer, a filtered array of calibrated aluminum x-ray diodes, a time resolved x-ray imager, a five-channel Dante for soft x-rays and time resolved backscatter measurements.

The gas jet was capable of producing densities in excess of $4x10^{19}$ atoms/cm$^3$ with the FWHM of the density profile of approximately 2 mm. This corresponds to an $n_e/n_{crit}$ of 0.15-0.2 assuming that the krypton is ionized to the L-shell ($n_e \sim 10^{21}$ /cm$^3$). The observed gas density profile in the supersonic jet duplicates our 2-D gas dynamic calculations. We will show that 2-D laser radiation hydrodynamic calculations of the interaction of the laser with the krypton jet matches the observed spatial emission profiles as recorded by the time resolved x-ray imager. We will discuss the recent experiments at HELEN and compare results with 2-D computer simulations.

# Multi-keV X-ray Emission from Underdense Gas Targets Irradiated with 532 nm and 351 nm Laser Light

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Jacob Grun
Naval Research Laboratory, Washington, DC

John Davis
Alme & Associates, Alexandria, VA

Kevin Oades, Mark Stevenson, Gary Slark
Atomic Weapons Establishment Plc, Aldermaston, U.K

A complementary series of experiments has been performed at the University of Rochester's OMEGA laser and at the Atomic Weapons Establishment's HELEN laser in which underdense gaseous targets composed of Kr, Ar, and Xe were irradiated with the goal of characterizing and optimizing the multi-keV x-ray emission. X-rays are efficiently produced in this manner by means of bleaching wave laser propagation in the underdense plasma, enabling their use for materials testing and backlighters. This is of special interest when scaled to the next generation of high power lasers such as the National Ignition Facility and the Laser Megajoule Facility.

We have successfully demonstrated efficient multi-keV x-ray production from both L-shell (Kr and Xe) and K-shell (Ar) radiators using 35 nm (3ω) light at the OMEGA laser and have initiated a comparison study using 532 nm (2ω) light at the Helen laser. Targets included Be cans and gasbags filled with Kr, Ar, and Xe gas at densities ranging from 0.1 to 0.3 of critical density. Conversion of the incident laser light to multi-keV x-rays has been observed to be more than an order of magnitude higher than solid targets [1] and is in reasonable agreement with simulations. We discuss the results of recent experiments at OMEGA and HELEN and compare conversion efficiencies measured for 3ω and 2ω laser light.

1. C.A. Back, J. Grun, C. Decker, L.J. Suter, J. Davis, O.L. Landen, R. Wallace, W.W. Hsing, J.M. Laming, U. Feldman, M.C. Miller, and C. Wuest, "Efficient Multi-keV Underdense Laser-Produced Plasma Radiators," *Phys. Rev. Lett.* (to be published 2001).

# Application of an unpublished Marshak wave solution to an experiment on x-ray transport in a heated foam cylinder*

M. D. Rosen, J. H. Hammer and M. C. Herrmann

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Conventional wisdom has it that analytic Marshak wave solutions exist only for boundary temperature sources that rise in time with either a power law or exponential behavior. There is, in fact, an unpublished exact solution for the supersonic radiation diffusion wave by L. Henyey (LLNL, 1954) that allows for a source that rises and then falls in time. We present that solution and apply it successfully to a recent experiment on diffusive supersonic x-ray transport in radiatively heated foam cylinders (Back et. al. Physics of Plasmas, 7, 2126 (2000)).

• Work performed under the auspices of the United States Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

Louis Henyey + William Grassberger
UCRL - 4428 (12/16/54)

# Abstract

Green light laser-plasma interaction experiments on Helen

L. Suter, R. Kirkwood, M. Miller, E. Williams, P. Young
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K. Oades, G. Slark, M. Stevenson, J. Foster
AWE, Aldermaston, UK

We report on the results of experiments using the Helen laser to irradiate gas bags and gas filled hohlraums with 2w light to study backscattering and hot electron generation. We contrast these findings to what we might expect based on our 3w data base.

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

Prefer poster session

# Regime for a Self-ionizing Raman Laser Pulse Compressor

Daniel S. Clark * Nathaniel J. Fisch

*Princeton Plasma Physics Laboratory*

**Abstract**

Backward Raman amplification and compression at high power might occur if a long pumping laser pulse is passed through a plasma to interact resonantly with a counter-propagating short seed pulse [V. M. Malkin, et al., Phys. Rev. Lett., 82(22):4448–4451, 1999]. One critical issue, however, is that the pumping pulse may suffer from an unacceptable level of spontaneous Raman backscatter from fluctuations intrinsic in the amplifying plasma medium, and therefore limit the power which may be usefully transferred to the short pulse. Backscatter from noise may be limited by making use of detuning, for example, through the use of a chirped pump laser or a plasma density gradient [V. M. Malkin, et al., Phys. Rev. Lett., 84(6):1208–1211, 2000]. Another means of avoiding deterioration of the pump is to employ a gaseous medium with pump intensities too low to ionize the medium, but with seed pulses sufficiently powerful to photoionize the gas. While the Raman interaction is then constrained only to the useful region near the amplifying seed, only rather low-power pumps can be used. Photoionization also introduces a damping of the short pulse which must be overcome by the Raman growth rate for net amplification to occur. The parameter space of gas densities, laser wavelengths, and laser intensities is surveyed to identify favorable regimes for this effect.

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# The weakly damped electron acoustic mode: Who ordered that?

**Harvey A. Rose*, Los Alamos National Laboratory**

Unlike the plasma waves on the Bohm-Gross branch[1] of the linear electron plasma wave dispersion relation, which when weakly coupled to light waves allow for wavenumber and frequency matching and thus SRS, the electron acoustic branch of the nonlinear dispersion relation[2] has no counterpart in linear theory about thermal equilibrium, and therefore no such thermal fluctuations. Once established, the electron acoustic wave will persist if its bounce frequency, $\omega_b$, is large compared to the rate at which trapped electrons are lost from the wave troughs. This loss may be due to residual collisional damping, or convective loss out the side of a laser intensity hot spot, or residual wave incoherence.

In this strongly trapped regime, the standard mode coupling theories of stimulated scatter fail. This can happed for very small wave amplitudes since $\omega_b / \omega_p = k\lambda_D(e\phi/T_e)^{1/2}$, where $\phi$ is the wave potential. Instead, it may be possible to use the near BGK modes selected by the stimulated scatter process, together with the scattered light, as a basis. The existence of an electron acoustic BGK mode, and the possibility of stimulated electron acoustic scatter (SEAS) may be inferred from the frequency dependence of the electron pressure. Its residual damping due to convective loss of trapped electrons may be calculated perturbatively. It is argued that this damping is less for the case of scatter from an RPP smoothed laser beam, than from an isolated hot spot. This is consistent with data[3] which shows more SEAS in the former case.

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

[1] D. Bohm and E. P. Gross, Phys. Rev. **75**, 1851 (1949).
[2] J. P. Holloway and J. J. Dorning, Phys. Lett. **138**, 279 (1989).
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31st Annual Anomalous Absorption Conference
Sedona, AZ, June 3rd-8th, 2001

# Observation of stimulated electron acoustic wave scattering: the case for nonlinear kinetic effects

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Electrostatic waves with a frequency and phase velocity between an ion acoustic wave (IAW) and an electron plasma wave (EPW) have been observed with Thomson scattering in inhomogeneous plasmas, and in the backscattered spectrum for homogeneous single hot spot laser plasmas. We show that these waves are consistent an electron-acoustic wave (EAW) that is a BGK-like mode due to electron trapping. The nonlinear dispersion relation for BGK-like EPW and EAW is discussed, and previous inhomogeneous Trident and Nova data are re-examined in this context. The implications of these results for backscattered SRS on the NIF are discussed.

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# Scaling of the SRS reflectivity of a single hot spot laser beam with laser intensity*

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Stimulated Raman back scattering (SRS) of a diffraction-limited laser beam incident on a preformed, long scale plasma has been studied at the Trident laser facility at Los Alamos National Laboratory. The plasma is formed by a Trident beam at a frequency of 527 nm that is line-focused at constant power for 1.2 ns on a CH target 6.7 $\mu$m in thickness and 1 mm in diameter. The plasma has been extensively characterized [1] and found to be homogeneous within the spatial scale of the interaction beam. The interaction beam, typically *f/4.5* has also been characterized extensively, and found to be nearly diffraction limited. The interaction beam pulse is a 0.2 ns Gaussian that is turned on 0.4 ns after the end of the formation pulse, in order to promote plasma quiescence. In spite of strong thermal effects, it is believed that beam propagation in these plasmas is reasonably well understood, except in the most extreme conditions when filamentation becomes dominant and the validity of the thermal conduction model breaks down [2].

The results from a study of the scaling of the SRS laser reflectivity versus laser intensity are presented in this paper. For this study, the peak intensity of the interaction beam has been changed over the range of 1—10 $\times$ $10^{15}$ W/cm$^2$. The plasma density for this study is kept constant. It corresponds to $k\lambda_D \approx 0.35$ for the Raman daughter plasma wave, and it has been chosen so that filamentation is not dominant. As the intensity is increased, the reflectivity has a sharp onset at ~ $10^{15}$ W/cm$^2$ and quickly saturates with further increases in intensity at a value of ~ 5%. However, the best fluid-based modeling available to us, assuming Landau damping rates for the plasma wave, indicates that the onset intensity should be about a factor of 7 higher than observed, and the reflectivity should not saturate at the level that it does. These data indicate the presence of kinetic effects that depress the plasma wave damping much below linear theory predictions.

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* This work is supported by the US DOE

[1] Montgomery *et al.,* Laser and Part. Beams **17**, 349 (1999)
[2] Montgomery *et al.,* Phys. Rev. Lett. **84**, 678 (2000).

# Kinetic and Non-kinetic Regimes of SRS Nonlinear Saturation*

**H.X. Vu and B. Bezzerides**
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**D.F. Dubois**
**280 Chamisa**
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The evolution of the stimulated Raman scatter instability (SRS) towards its saturated state can occur by several, oftentimes, nonlinearly coupled physical mechanisms. Our work shows that in the parameter space defined by $I_0$, the incident laser intensity, and $k\lambda_D$, where $k$ is the wave-number of the linearly fastest growing mode, there exists domains where the saturated state is established by a physical mechanism which is distinct in its features, thereby offering the promise that it can be understood by a simple dynamical model. For $k\lambda_D < 0.17$ and $I_0 < 10^{15}$ Watts/cm$^2$, our simulations with the reduced particle-in-cell (RPIC) code confirm the validity of the well-know Zakharov model, including the effects of the Langmuir decay instability (LDI), cascade, and Langmuir collapse. For higher $k\lambda_D$, we have identified, for the first time, a new regime marked by the importance of electron trapping. On the one hand, electron trapping leads to a reduction of the Langmuir wave (LW) damping, thereby assisting the overall growth. On the other hand, electron trapping leads to the development of a nonlinear frequency shift that ultimately saturates the instability. It is this regime whose understanding is crucial to the success of applications proposed for the National Ignition Facility. In this talk, we present simulation results exhibiting the main features of this new regime: (1) a LW spectrum with a narrow spectral width, (2) much larger backscatter SRS (BSRS) than predicted by the Zakharov model with its fixed Landau damping, (3) an intermittent flattening of the electron distribution function near the primary excited LW phase velocity with an extended hot-electron tail, (4) pulse-like reflectivity ($t_{pulse}$<1ps) with no steady-state so long as stimulated Brillouin scatter is small, and (5) significant BSRS even for $k\lambda_D \sim 0.45$. We present an analytic theory of the pulse-like behavior which involves the competition of the time-dependent, trapping-induced, frequency shift and the parametric regeneration. This model follows from previous work of Morales and O'Neil,[1] and Cohen and Kaufman.[2]

Strictly speaking, the effects of trapping are most easily understood within the context of a collisionless, 1D plasma. We have investigated the impact of higher dimensions both by a full 2D simulation and by a simple numerical model that accounts for loss of trapped particles due to transverse thermal motion, and find that the same qualitative features remain. In an attempt to model the collisional environment of recent Trident experiments, we present preliminary results implementing a DLM velocity distribution for the electrons.

* H.X. Vu and B. Bezzerides are supported by the Los Alamos Inertial Fusion & Radiation Physics Program.

1. G.J. Morales and T.M. O'Neil, Phys. Rev. Lett. **28**, 417 (1972).
2. Bruce Cohen and Alan N. Kaufman, Phys. Fluids **21**, 404 (1978).

# Observation of Multiple Cascade Steps of the Langmuir Decay Instability in a Laser Plasma

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## Abstract

Parametric laser-plasma interactions play an important role in the success of inertial confinement fusion (ICF). Stimulated Raman scattering (SRS) is one such interaction and involves the resonant decay of an incident electromagnetic wave (EMW) into a scattered EMW and an electron plasma (or Langmuir) wave (EPW).

The EPW amplitude can be large for moderate SRS reflectivity so that saturation by nonlinear mechanisms is expected. One such mechanism is the Langmuir decay instability (LDI), in which the daughter Langmuir wave from SRS decays into a secondary Langmuir wave and an ion acoustic wave (IAW). LDI occurs when the amplitude of the primary EPW exceeds a threshold that is proportional to the damping rates for the secondary EPW and IAW. The growth rate for LDI is maximized when the daughter EPW and IAW are propagating antiparallel and parallel, respectively, to the primary Langmuir wave. Subsequent Langmuir wave decays are possible if their amplitudes exceed the threshold. We use the terminology that multiple LDI decay steps are collectively called LDI cascade. LDI cascade can saturate SRS since wave energy from the SRS EPW couples into secondary EPWs that are non-resonant with the SRS process.

We present results from the sixth in a series of experiments designed to investigate the interaction of a single laser hot spot, or speckle, with a quasi-homogeneous plasma. The experiment was conducted at the Los Alamos National Laboratory (LANL) using the TRIDENT laser facility. Electron plasma waves driven by stimulated Raman scattering (SRS) in a laser-produced plasma were measured using collective Thomson scattering. Multiple waves were observed whose frequency and spacing is consistent with cascade steps from the Langmuir decay instability (LDI). Multiple cascade steps are inferred from the spectrum. The experimental setup is described and the Thomson scattered spectra are well correlated with measurements of the backscattered SRS light.

This work was supported by Los Alamos National Laboratory (LANL) Contract E29060017-8F.

# Cyclic plasma shearing interferometry for temporal characterization of a laser-produced plasma

J. A. Cobble, R. P. Johnson, N. A. Kurnit, D. S. Montgomery
*Los Alamos National Laboratory*

A cyclic shearing interferometer has been employed to characterize a laser-produced plasma with 180-ps resolution. Counter-propagation maintains an equal path length for the probe and reference beams, and the shear is provided solely by the plasma which appears in the circuit after the reference beam has passed. The background is virtually fringe free on account of the stability so that analysis is very easy. The line-focused plasma is seen to expand in a cylindrical manner with an exponential density profile. The plasma, which was penetrated by an interaction beam along its length, was probed with the interferometer to look for evidence of a bow shock. No macroscopic evidence for the bow shock is seen.

LA-UR-01-2226

# The Leopard Petawatt Laser System

B.S. Bauer, S. Fuelling, J. Glassman, V.L. Kantsyrev, N. Le Galloudec, V. Makhin, R. Presura, A.S. Shlyaptseva, V.I. Sotnikov, F. Winterberg, A. Astanovitskiy, S. Batie, W. Brinsmead, H. Faretto, B. Le Galloudec, A. Oxner, J. Ludwick, S. Rogowski, and J. Sturtz

*Physics Department, University of Nevada, Reno*

The Petawatt laser is being transferred from Lawrence Livermore National Laboratory (LLNL) to the Nevada Terawatt Facility (NTF) at the University of Nevada Reno (UNR). The parameters of this laser are: maximum power > 1000 TW; maximum energy 680 J; pulse duration 0.44-20 ps; wavelength 1054 nm; beam focused with an on-axis f/3 parabolic mirror from a diameter of 58 cm to a minimum spot of 9 microns FWHM; peak intensity $3 \times 10^{20}$ W/cm$^2$; 50 micron target pointing accuracy; 0.4-J prepulse 2 ns before the main pulse; and 0.1-J ASE in the 4 ns before the main pulse. The Petawatt beam will be used in conjunction with two auxiliary high-energy-density drivers: a flexibly oriented, kJ/TW-class, 20-cm-diameter, 1054-nm/527-nm-wavelength laser (under development) and a 1-MA, 200-kJ, 2-MV, 2-TW, 80-ns rise-time z-pinch (Zebra, currently in operation). The Zebra z-pinch can be made to produce compressed matter, strongly magnetized plasma, intense radiation, energetic electron beams, and a variety of other conditions, including hot dense plasma of almost any material. Available target diagnostics include time-resolved x-ray imaging, x-ray polarization imaging spectroscopy, laser shadowgraphy, and time-resolved optical imaging spectroscopy. Experiments with the Petawatt laser will help better understand the energy deposition of extremely intense laser light in dense plasma, to assist in the design of petawatt diagnostic and fast-ignitor systems for Omega (LLE) and NIF (LLNL), and to develop high-resolution flash x-ray and proton radiography. Other exciting research areas that could be addressed include equations of state, material properties, hydrodynamics, radiation physics, plasma physics, relativistic self-focusing and filamentation, strongly driven instabilities, harmonic generation, ultrahigh magnetic fields, x-ray lasers, and laboratory astrophysics. A user-friendly facility will be developed to help many researchers investigate and exploit the extreme regimes created by the Petawatt laser.

# Non-LTE databases for hydrodynamic simulations of laser produced plasmas .

A. Bar-Shalom, M. Klapisch and J. Oreg
ARTEP, inc. Columbia, MD 21044

The SCROLL model[1, 2] for calculating non-LTE absorption and emission spectra was extended to create non-LTE databases that will be used in hydrodynamic simulations of laser produced plasmas with FAST[3] through table look-up. SCROLL is a collisional radiative model based on super configurations as effective levels. The rate coefficients are calculated with Dirac wavefunctions, using partition function algebra[4] and assuming LTE populations at an effective ionization temperature $T_z$ within superconfigurations. $T_z$ is the temperature that would give in LTE the same average charge Z*. The rates for radiative processes depend on the local radiation field that has to be parameterized. Defining $T_r$ as an opacity-weighted radiation temperature, we find three regimes:

(1)$T_r < T_z$ The effect of the radiation on the opacity spectra is negligible.

(2)$T_z < T_r < T_e$ The effect of radiation on the rates and opacities can be described by a Planckian related to $T_r$.

(3) $T_r > T_e$ The opacities reduce to LTE at $T_r$. and can be calculated by the STA LTE ode.

For the target design at NRL regime 1 applies to high-Z thin layers, and non-LTE databases can be calculated in the optically thin approximation.

The preparation of the databases in all three regimes will be described. Examples will be discussed.

This work was supported by the USDOE under contract with the Naval Research Laboratory, Laser Plasma Branch.

[1] A. Bar-Shalom, J. Oreg and M. Klapisch, **56**, R70 (1997).

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P1-19

# Inference of hohlraum temperature, albedo, and conversion efficiency via temporally- and spatially resolved x-ray re-emission measurements

R. E. Olson, W. A. Stygar, R. J. Leeper
Sandia National Laboratories
Albuquerque, NM 87185

The time-resolved measurement of x-ray re-emission from the interior wall of a hohlraum can be accomplished with techniques involving K- and L- edge filtered photocathode x-ray detector (XRD) arrays[1] or achromatically filtered photoconductive detectors (PCD)[2]. Spatially-resolved measurements of hohlraum x-ray re-emission can be made with soft x-ray framing cameras (XRFC)[3] using strip-line activated microchannel plates, phosphor screens and either film or CCD readout. If the XRD/PCD power measurements are done in a co-linear fashion with a XRFC, temporally- and spatially resolved re-emission temperature measurements of a hohlraum wall can be obtained[4]. In addition, if the formulae derived in Ref. 5 are invoked, time-resolved inferences of the radiation drive, hohlraum wall albedo, and x-ray conversion efficiency can also be obtained. In the present work, XRD, PCD, and XRFC data from recent hohlraum experiments performed at the Z and Omega facilities will be used to describe the process for obtaining the hohlraum albedo, efficiency, and spatially-resolved temperature information.

[1]H. N. Kornblum, *et al.*, Rev. Sci. Instrum., 57, 2179 (1986).
[2]R. E. Turner, *et al.*, Rev. Sci. Instrum., 70, 656 (1999).
[3]F. Ze, *et al.*, Rev. Sci. Instrum., 63,5124 (1992).
[4]R. E. Olson, *et al.*, Rev. Sci. Instrum., 72, 1214 (2001).
[5]W. A. Stygar, R. E. Olson, R. B. Spielman, R. J. Leeper, "Analytic models of high temperature hohlraums," to be published, Phys. Rev. E. (2001).

*Sandia is a multi-program laboratory operated by the Sandia Corporation, a Lockheed Martin Company, for the U. S. Department of Energy under Contract No. DE-AC04-94AL85000.

# A comparison of shock velocity and x-ray re-emission measurements of radiation temperature in Omega hohlraum experiments

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In collaboration with *Los Alamos National Laboratory*, *Lawrence Livermore National Laboratory*, and the *University of Rochester Laboratory for Laser Energetics*, we have performed a series of hohlraum experiments at the Omega laser facility. The experiments utilize 15 beams of the Omega Laser to heat halfraums (i.e., cylindrical hohlraums with one laser entrance hole) to radiation temperatures of ~160 eV. Time-resolved measurements of x-ray re-emission from the interior wall of the halfraum are made with the "Dante" K- and L- edge filtered photocathode detector array[1] and achromatically filtered photoconductive detectors (PCD)[2]. Time- and spatially-resolved measurements of the breakout of a x-ray driven shock through ablator samples exposed to the halfraum radiation environment are made with a streaked optical pyrometer (SOP)[3]. When combined with radiation hydrodymic code calculations, the shock breakout measurement can be used to infer radiation temperature in the halfraum. In the present work, the Dante, PCD, and SOP data will be used together with 2D integrated radiation hydrodynamic code calculations to provide a comparison between the two independent methods of hohlraum temperature measurement and to provide an assessment of the accuracy of the radiation hydrodymic code calculations.

[1]H. N. Kornblum, *et al..*, Rev. Sci. Instrum., 57, 2179 (1986).
[2]R. E. Turner, *et al..*, Rev. Sci. Instrum., 70, 656 (1999).
[3]J. A. Oertel, *et al..*, Rev. Sci. Instrum., 70, 803 (1999).

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*Sandia is a multi-program laboratory operated by the Sandia Corporation, a Lockheed Martin Company, for the U. S. Department of Energy under Contract No. DE-AC04-94AL85000.

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# 31st Annual
# Anomalous Absorption Conference

## Tuesday, June 5, 2001

| | |
|---|---|
| **9:00 a.m. – 12:20 p.m.** | **Oral Session 2** |
| **12:20 p.m.** | **Lunch** |
| **7:30 p.m. – 8:30 p.m.** | **Review Session 2, Invited Talk:<br>Dr. William Zajc,<br>"Quark-gluon plasmas:<br>initial results from RHIC"** |
| **8:30 p.m. – 11:00 p.m.** | **Poster Session 2** |

31st Annual Anomalous Absorption Conference
Sedona Az.
June 4-9, 2001

**Scaling of Energy Transfer Between Crossing Laser Beams with Beam Intensity and Plasma Size and Density**

Bob

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Recent experiments in which energy is transferred between two beams of the Omega laser that cross in a plasma with a sonic flow have investigated the scaling of the energy transfer process with beam intensity, density, and the size of the interaction volume. The experiments use a CH foil target that is pre-heated by as many as 28 of the Omega beams to produce plasma conditions that are similar to what is expected in indirect drive ignition experiments. Two interactions beams (pump and probe) are directed nearly parallel to the foil surface and cross at a ~ 25° angle (forward scatter) at a point 350 microns above the foil surface where the plasma is flowing outwards at a speed of ~ Mach 1. Earlier work has established that ion waves are resonantly driven and scatter energy from one beam to the other, with the energy transferring in the same direction as the plasma flow [1,2]. We observe energy transfer in the present case with a maximum amplification of the low energy probe beam of x ~ 1.8 in the presence of a $7 \times 10^{14}$ W/cm$^2$ pump beam. When the pump intensity is decreased we find that the probe amplification decreases slowly, persisting down to $1 \times 10^{14}$ W/cm$^2$, below which value energy transfer is found to be negligible. These experiments will be discussed along with further work investigating the scaling of energy transfer with density and scale size.

[1] R. K. Kirkwood et al. Phys. of Plasmas 4, 1800 (1997).
[2] K.B. Wharton, et. al. Phys. Rev. Lett. 81, 2248 (1998).

Work performed for US DoE under contract# W7405-ENG-48

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Prefer oral session , on Monday, Tuesday, or Wednesday of the conference week.

# Direct observation of mass oscillations due to ablative Richtmyer-Meshkov instability and feedout in planar plastic targets

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**Abstract**

The perturbations that seed the Rayleigh-Taylor (RT) instability in laser-driven targets form during the early-time period that includes a shock wave transit from the front to the rear surface of the target, and a rarefaction wave transit in the opposite direction. During this time interval, the areal mass perturbations caused by all sources of non-uniformity (laser imprint, surface ripple) are expected to oscillate. We report the first direct experimental observations of the areal mass oscillations due to ablative Richtmyer-Meshkov (RM) instability (front surface ripple) and feedout (rear surface ripple) followed by the monotonic RT growth of areal mass variation. Our experiments were made with 40 μm to 90 μm thick CH targets rippled either at the front or at the rear side, the ripple wavelength being either 30 or 45 μm, and the sine wave amplitude - 0.5, 1 or 1.5 μm. The targets were irradiated with 4 ns long Nike KrF laser pulses at ~80 $TW/cm^2$. The oscillations were observed with our novel diagnostic technique - monochromatic x-ray imaging coupled to a streak camera. For ablative RM, we observed the mass variation to grow, reach a peak, and then decrease, after which the exponential RT growth begins. For the feedout geometry, we observed a distinct half-oscillation (two phase reversals), also followed by the onset of the RT growth.

Work supported by the U.S. Department of Energy.

Prefer Oral

# Areal mass oscillations in laser-driven plastic targets due to ablative Richtmyer-Meshkov instability and feedout: theory and simulations

A. L. Velikovich,[1] Y. Aglitskiy,[2] A. J. Schmitt,[1] J. H. Gardner,[3] N. Metzler,[2] M. Karasik,[1] S. P. Obenschain,[1] V. Serlin,[1] C. Pawley,[1]

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## Abstract

The growth rates of the ablative Rayleigh-Taylor (RT) instability have been measured in numerous experiments starting from mid-1980s. Much less experimental results are available to quantify the linear relationships between the measurable initial non-uniformities and the seed mode amplitudes. Most of our knowledge in this field still comes from simulations and theory, which predict mass perturbations to oscillate during the shock-rarefaction transit time when the RT seeds are formed. In the case of a planar target rippled at the front side, the oscillations characteristic of the so-called ablative Richtmyer-Meshkov (RM) instability [1, 2] are driven by the "rocket effect," or the dynamic overpressure in the ablated plasma. In a planar target rippled from the rear side (feedout [3, 4]), the competition between the lateral mass redistribution in a reflected rippled rarefaction wave, which reverses the phase of mass modulation, and the RT growth, which starts where the target is initially thinner and tends to further decrease the areal mass there, causes the observable oscillations. We discuss theory and simulations of the non-monotonic evolution of areal mass perturbations in an ablatively driven target during the shock-rarefaction transit, which were observed for the first time in recent experiments on Nike laser at NRL.

Work supported by the U. S. Department of Energy.

[1] A. L. Velikovich *et al.*, Phys. Plasmas **5**, 1491 (1998).
[2] V. N. Goncharov, Phys. Rev. Lett. **82**, 2091 (1999).
[3] D. P. Smitherman *et al.*, Phys. Plasmas **6**, 932 (1999).
[4] A. L. Velikovich *et al.*, Phys. Plasmas **8**, 592 (2001).

Prefer Oral

# Measurements of Growth Rates in Laser-Driven Rayleigh-Taylor Instability

H. Shiraga, M. Nakai, K. Shigemori, H. Azechi, M. Nishikino, T. Sakaiya, S. Fujioka, Y. Tamari, N. Miyanaga, H. Nishimura, K. Nishihara, A. Sunahara, H. Takabe, H. Nagatomo, and T. Yamanaka
Institute of Laser Engineering, Osaka University

Growth rate of the Rayleigh-Taylor instability in 0.53-μm–laser-irradiated planer plastic targets were measured by using Moire interferometer technique for the wavelength down to 5 μm. Results are in good agreement with values estimated from hydrodynamic code calculation with non-local electron heat transport.

LA-UR-01-2332

ANOMALOUS ABSORPTION CONFERENCE
June 4-8, 2001
Sedona, AZ

**Further Adventures in Convergent Mix**

C. W. Barnes, S. H. Batha, N. E. Lanier, G. R. Magelssen, J. M. Scott, R. L. Holmes, T. J. Murphy (Los Alamos National Laboratory)
S. Rothman, A. M. Dunne, K. Parker, D. L. Youngs (Atomic Weapons Establishment)

Directly driven cylindrical experiments on the OMEGA laser system have proven to be a useful geometry for measuring the development of mix in Richtmyer-Meshkov unstable systems under compressible, miscible, convergent, strong-shock conditions. Experimentally, we have measured the increase of the mixing zone width during the coasting phase of the implosion. The measurements support the picture of the mix layer growing due to mix rather than because of preheating of the marker layer. The initial surface finish of the marker layer also affects the amount of mixing that occurs. The surface finish was varied over three orders of magnitude and demonstrated that rougher surfaces do indeed create more mix than smoother surfaces. Various foam densities have been used to vary the back-pressure of the implosion and to confirm the absence of Rayleigh-Taylor contribution to the mix. This technique has also been extended to study mix between two cylinders by placing a solid wire at the center of the cylinder.

This document was produced by the Los Alamos National Laboratory under the auspices of the United States Department of Energy under contract no. W-7405-ENG-36.

inexpensive.
Blewitt
~1cm 3½ us
→ 100 um
mix.

Direct-drive

① Do you follow motion to peak comp.?

LA-UR-01-2333

ANOMALOUS ABSORPTION CONFERENCE
June 4-8, 2001
Sedona, AZ

# Observation of Mix in a Compressible Plasma in a Convergent Cylindrical Geometry

S. H. Batha, C. W. Barnes, N. E. Lanier, G. R. Magelssen, J. M. Scott, R. L. Holmes, T. J. Murphy (Los Alamos National Laboratory)
S. Rothman, A. M. Dunne, K. Parker, D. L. Youngs (Atomic Weapons Establishment)

Mixing of two materials may occur when the interface between them is shocked or accelerated. The mixing is exacerbated when the interface is imploding, highlighting the important effects of compressibility, miscibility, and convergence under strong-shock conditions. We present experiments and simulations of mix occurring in convergent cylindrical geometry. A hollow plastic 1-mm-diameter cylinder is imploded by ≈20 kJ of 351-nm laser light in a 1-ns square pulse from the OMEGA laser. The cylinder is filled with low-density foam that provides a back-pressure to the implosion. A higher density "marker layer" is placed at the interface between the plastic and foam. Both the plastic/marker and marker/foam interfaces are Richtmyer-Meshkov unstable. The marker material is chosen to produce either a large or small amount of mix. Experimentally, we measured the radial extent of the radiographically opaque marker layer. We found that the simulations were in excellent agreement in both cases with the experiments.

This document was produced by the Los Alamos National Laboratory under the auspices of the United States Department of Energy under contract no. W-7405-ENG-36.

# Feasibility of Fluorescence-Based Imaging for Turbulence and Mix Studies in Compressible, Convergent Implosions

N. E. Lanier and Cris W. Barnes

A recent study investigating the feasibility of fluorescent-based imaging has been conducted for application in compressible, convergent implosions on OMEGA. Fluorescent-based imaging offers several advantages over traditional radiography, the most notable being enhanced measurement localization. The technique employs a standard backlighter to illuminate an experimental package causing a strategically placed dopant to fluoresce. A natural extension of fluorescent-based imaging is point imaging velocimetry (PIV). PIV requires the fluorescent dopants be inserted into the experimental package as localized pellets, which upon illumination, fluoresce and appear as bright spots when imaged. By taking successive images in time, the motions of these spots can be followed, and velocity flow information can be extracted. We report on the applicability of fluorescent-based imaging and PIV on direct-drive cylinder implosions on OMEGA.

# Current Status of Tertiary Neutron Diagnostic by Carbon Activation

V. Yu. Glebov, D. D. Meyerhofer, P. B. Radha, W. Seka, S. Skupsky, J. M. Soures, and C. Stoeckl

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S. Padalino, L. Baumgart, R. Colburn, and J. Fuschino
State University of New York at Geneseo

T. C. Sangster
Lawrence Livermore National Laboratory

The yield of tertiary neutrons with energies greater than 20 MeV has been proposed as a method of determining the $\rho R$ of ICF targets. Carbon has been chosen as an activation material because of its high reaction threshold and the availability of high-purity samples.

The $(n, 2n)$ reaction in $^{12}C$ has a threshold of about 19 MeV. The product of this reaction, $^{11}C$, has a half-life of 20.3 min and emits a positron, resulting in the production of two 511-keV gamma rays upon annihilation. The positron decay of $^{11}C$ is identical to that in copper activation, which is used as a measure of 14.1-MeV primary DT yields; therefore, the present copper-activation gamma-detection system can be used to detect the tertiary-produced carbon activation. The main requirement for this diagnostic is to have a very pure carbon sample, free from any positron-emitting contamination.

The current status of carbon-activation diagnostic development at LLE will be presented together with experimental results and theoretical interpretation of several direct-drive implosion experiments with carbon-activation diagnostic on OMEGA.

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

Prefer oral session

Title

# Laser generated shocks for dynamic material strength and phase studies for ICF

Authors:

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Plasma Physics, P-24
Los Alamos National Laboratory
Los Alamos, New Mexico USA

Abstract

Interferometry, and transient x-ray diffraction (TXD) are used to study the dynamic material response to shock loading by direct laser irradiation and impact by laser-launched plates. The Los Alamos Trident laser is one of several lasers that have been used to generate shocks of 10 Kbar to several Mbar in single crystal and polycrystalline materials of interest to ICF. Incorporating optical velocity interferometry (line-VISAR and point-VISAR) with transient x-ray diffraction can provide a complete understanding of the dynamic material response to shock compression and release. We will describe the experimental equipment and techniques used to collect these dynamic materials data.

Submitted to: Anomalous Absorption Conference2001, Sedona, AZ

**Review Session 2**

**Tuesday, June 5, 2001**

**7:30 - 8:30 p.m.**

# Quark-gluon plasmas: initial results from RHIC

## Wiliam A. Zajc
Professor of Physics, Columbia University, NY, NY; Spokes-person for the PHENIX experiment at the RHIC facility.

Abstract: In June 2000, Brookhaven National Laboratory's Relativistic Heavy Ion Collider (RHIC) began operations. Beams of fully stripped Au nuclei were at 65 GeV per nucleon were brought into collision with counter-rotating beams of the same energy, to provide the world's highest energy nuclear collisions. Four experiments were deployed around the accelerator ring to study particles emerging from these collisions. A primary goal of this study is the creation and characterization of quark-gluon plasma (QGP), a deconfined state of quarks and gluons similar to the state of the universe a few microseconds after the Big Bang. I will report on the status of the accelerator, the experiments, and the prospects for QGP detection.

**Poster Session 2**

**Tuesday, June 5, 2001**

**8:30 – 11:00 p.m.**

# Exact kinetic solutions for nonisothermal plasma expansion

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The physics of ion acceleration in laser-produced plasmas is one of intensively discussed subjects because of its vital importance for various applications such as inertial confinement fusion, particle accelerators, nuclear physics, medicine, etc. Though the basic elements of ion acceleration in an expanding plasma cloud have been described many years ago[1,2], the recent experiments with the sub-picosecond pulse lasers of high intensity[3] and experiments with nanosecond-pulse lasers[4] involving new diagnostic techniques report on ion energies far above the predicted cutoff. An exact kinetic solution for plasma expansion in vacuum has been found recently[5]. However it is valid for a limited set of initial conditions where ions and electrons have the same spatial and velocity distribution functions and the electrostatic potential has a quadratic spatial dependence. We present here a new, more general solution to the problem of a quasi-neutral plasma expansion, which is an exact analytical initial value (Cauchy) solution to the system of coupled electron and ion Vlasov kinetic equations. The main advantage of this solution is that no *a priori* assumptions have been made about the spatial profile of the electrostatic potential. This solution is based on a novel technique of the renormalization group symmetries for the system of kinetic equations for electrons and ions along with the quasi-neutrality condition.

Our solution includes as a particular case the previous solutions[5] and it allows to consider more general situations where electrons and ions initially have different distribution functions. In opposite to the previously known case of the isothermal expansion[1], our solution accounts for the effect of adiabatic cooling of both plasma species and because of that the ions are accelerated to a certain finite energy. This high energy cutoff of the ion spectrum is analyzed and its dependence on the initial conditions will be discussed in relation with the recent experimental results[3].

This work is partly supported by the Russian Foundation for Basic Research.

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[1] A. V. Gurevich *et al.*, Sov. Phys. JETP **22**, 449 (1966).
[2] S. J. Gitomer *et al.*, Phys. Fluids **29**, 2679 (1986).
[3] J. Zweiback *et al.*, Phys. Rev. Lett. **84**, 2634 (2000).
[4] D. G. Hicks *et al.*, Phys. Plasmas **8**, 606 (2001).
[5] D. S. Dorozhkina and V. E. Semenov, Phys. Rev. Lett. **81**, 2691 (1998).

# Instability of a driven ion acoustic wave in the fluid regime

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[4]INSTITUT DE PHYSIQUE FONDAMENTALE, UNIVERSITÉ DE BORDEAUX-1, 33405 TALENCE CEDEX, FRANCE

Nonlinear effects associated with ion acoustic waves (IAWs) are an important issue for parametric instabilities in laser-produced plasmas. Experiments and numerical simulations clearly suggest that the mechanisms of IAW decay[1], momentum deposition[2], and particle trapping[3] may all play an important role in the nonlinear evolution of the stimulated Brillouin and Raman instabilities.

In order to improve the understanding of these issues, we have investigated the stability of a coherently driven IAW. The effects of harmonic generation of the mother wave, of its dispersivity, of the driver frequency detuning, and of the coupling of the daughter wave to higher order satellites have been accounted for.

The theoretical analysis has been carried out assuming that the driver amplitude and the wave number are small parameters: $e\phi_d/T_e \ll 1$ and $k_d\lambda_D \ll 1$. A decay type instability has been found in the domain of long wavelength for the daughter waves, $k \ll k_d$, propagating in the near forward direction. The domain of instability has been analyzed as a function of the driver amplitude and the frequency detuning. Fully nonlinear simulations of driven ion acoustic waves have been performed in which the effect of momentum transfer to the plasma has been accounted for. The simulations have made it possible to extend the analytical results and to prove the possibility of ion acoustic energy transfer towards longer wavelengths. The effect of the IAW instability on SBS saturation will be discussed.

This work is partly supported by the Russian Foundation for Basic Research.

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# The .53μm Laser Option for Advanced Applications

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Use of the National Ignition Facility with green light as the output is an intriguing option for advanced applications ranging from inertial fusion[1] to production of x-ray sources. The viability of this option depends on how intense laser light couples with long scale length plasmas, a topic for which little data currently exists. For some estimates, we invoke a scaling modeling based on the dimensionless parameters which specify the behavior of a collisionless plasma. This enables us to use data for .35μm laser light to infer analogous results for .53μm light. We also present computer simulations of intense laser light interacting with a plasma with density near .25 $n_{cr}$ (the critical density), a regime particularly relevant for several green light applications. Simulations show significantly more absorption into hot electrons than would be inferred from the backward Raman signal. The heated electron temperatures can also be significantly different from estimates based on the plasma wave phase velocity. We touch base with some experiments in which plasmas with density near .25 $n_{cr}$ are irradiated with .53μm light[2] and suggest some experiments to test our hypotheses.

1. E.M. Campbell *et. al.*, Comments Plasma Phys. Cont. Fusion 18,201(1997)
2. L.S. Suter *et. al.*, paper this conference

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# Plasma Instability Channeling for Advanced Applications of High Power Lasers

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A way to proactively deal with laser-driven instabilities is to channel them into benign or desired outcomes. We explore a channeling scheme in which the desired outcome is to efficiently generate high-energy electrons (and x-rays) using $3w_0$ light. Seed beams of $2w_0$ light are used to induce scattering in the forward direction in a plasma of the appropriate density. In 1D and 2D computer simulations we can demonstrate significant absorption of the laser energy into hot electrons. In addition, by varying the angle between the beams the phase velocity of the electron plasma wave and the heated electron energies can be altered as well. This gives us the ability to produce an array of x-ray energies, broadening the usefulness of this technique.

Work supported by LLNL.... And by DTRA Contract RPH4J at the Naval Postgraduate School.

Cryogenic Gasbag experiments on NOVA

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In order to estimate the backscattering due to parametric instabilities in LMJ and NIF-like hohlraum gas plasmas, cryogenic gasbags were shot on NOVA in 1999. The good knowledge of the hydrodynamic parameters of such plasmas being essential for instability calculations, accurate simulations were performed and compared to the temperatures given by the Thomson scattering diagnostic.

# Fokker-Planck simulation of DT capsule implosions and hot-spot formation for ICF

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Numerical simulations of the implosion of DT capsules and ignition of thermonuclear reactions in ICF targets are routinely performed with large hydrodynamics codes using classical (Spitzer) modeling of ion thermal transport and viscosity. However, some past studies have shown that non classical, fully kinetic effects can dominate ion transport in such situations as shock wave propagation [1] or the implosion of gas-filled targets [2]. In this work, the possible occurrence of such effects in the implosion of ICF capsules is addressed by performing ion-kinetic simulations of that process with a Fokker-Planck code.

Our Fokker-Planck code "FPion" has been improved to simulate systems of macroscopic size, exhibiting large density and temperature variations in time and space, in 1-D spherical geometry. The code has been used to compute the final compression of the fuel between shock convergence and stagnation in LMJ-class ICF capsules, and results have been compared to standard 1-D hydrodynamics calculations of the same process using the code "FCI1". Detailed results of those calculations will be shown in this poster. To summarize the main features, the central hot-spot formation is found to proceed in a significantly different way in the kinetic simulation, reaching a higher ion temperature while the maximum $\rho$r of the surrounding dense fuel layer is decreased with respect to the reference hydro simulation. The consequences of these effects on the overall capsule yield are unclear, since the thermonuclear reactivity is expected to increase in the hot spot while the lower $\rho$r of the main fuel should decrease the final burn fraction.

Although a definite conclusion thus has to wait until more complete simulations including thermonuclear burn can be performed, it is nonetheless clear from the present results that ion-kinetic effects cannot be simply neglected, as it is often assumed.

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# Targets for laser-plasma interaction studies on the LIL facility

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The first experiments on the LIL facility, a prototype of the LMJ laser, will be carried out in two years or so. At that time, one of the 60 quadruplets will be available, and a first campaign on laser-plasma interaction is planned. In order to prepare this campaign, we are designing gas-filled cylindrical cavities irradiated along their symmetry axis. Two kinds of cavities are planned, with one and two windows, depending on the mechanisms we want to study. Cavities with a single window are intended to reproduce the plasma conditions encountered in a future megajoule cavity by an outer laser beam. Such a beam will mainly undergo Brillouin scattering. The two-window cavities are devoted to the study of inner laser beam scattering due to Raman instability. In addition to the understanding of parametric instabilities, varying the length and the width of the two types of target will allow us to estimate the spread of transmitted light due to the plasma hydrodynamics in megajoule-like conditions. We will present our results, including scaling laws for density, electron and ion temperatures, as a function of the dimension of the cavities, and we will estimate the effect of parametric instabilities with our post-processor, PIRANAH.

P2-8

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# Influence of filamentation and optical smoothing technics on speckles statistics in the FCI context

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The choice of an efficient optical smoothing method will be a key element for the success of megajoule class laser projects (NIF and LMJ projects). By controlling filamentation and beam bending by means of optical smoothing, a better homogeneity of laser irradiance can be obtained on target and Raman and Brillouin scatterings can be indirectly reduced. To adress this topic, we have used the parallel version of the 3D PARAX code that simulates the propagation of a light beam through a hot plasma within the framework of the paraxial approximation.

The different smoothing technics (Smoothing by Transverse Spectral Dispersion, Smoothing by Longitudinal Spectral Dispersion with RPP or KPP phase plate) are compared by studying self-focusing, beam spreading and self-smoothing. Speckles statistics (distribution function of speckle intensities, speckle lengths and speckle widths) is especially analyzed. Values in the focal spots are compared to analytical results. The influence of filamentation and self-focusing on the modification of speckles statistics is also investigated.

# Design of a Thomson scattering probe for the LIL facility

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The LIL (Ligne d'intégration Laser) facility, which is under construction in Bordeaux (France), will be used as a prototype of one of the LMJ beam. In its first configuration, the LIL laser will deliver only one quadruplet (four elementary beams) and will be used to perform laser-plasma interaction experiments. After this first period of exploitation, a second quadruplet will be set-up with the possibility of splitting the two quadruplets as to supply the LIL with eight beams. During this second phase, we are planning to use a Thomson scattering diagnostic as to measure the plasma parameters as well as for laser-plasma interaction experiments.

First studies on the design of the corresponding probe beam have been conducted and their results will be presented. The parameters that have been specified right now are the wavelength, the energy and duration of the beam, its angle of incidence with respect to the other beams as well as its smoothing technique. These specifications for the Thomson scattering probe beam are trying to take into account both types of applications for the diagnostic:

- ✓ Plasma characterization using thermal scattering
- ✓ Laser-plasma interaction experiments through scattering off stimulated waves (stimulated by the instabilities of one quadruplet or one of the split beams).

For the different specified parameters, we will present the method used for their definition in view of these two potential applications.

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P2-10

# Comparing partial beam simulations to whole beam simulations with pF3d

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Laser plasma interactions are sensitive to both the fine-scale speckle and the larger scale envelope intensity of the beam. For some time, simulations have been done on volumes taken from part of the laser beam cross-section, and the results of multiple simulations extrapolated to predict the behavior of the entire beam. The definitive method is to simulate the entire beam, but these calculations are only possible on massively parallel computers. Using the code pF3D, we present comparisons of whole (smoothed and aberrated) beam simulations with partial beam simulations and with extrapolations of partial beams to the full scale.

Preferred format: Poster

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# Modeling stimulated Raman backscatter

**Authors: R. L. Berger, R. Kirkwood, C. H. Still, and E. A. Williams**

The observed reflectivity of stimulated Raman (SRS) back scatter scales more weakly with laser and plasma parameters than one would expect from the linear gain dependence on laser intensity, plasma density, damping rates, or electron temperature. It is common to encounter explanations for significant reflectivity below nominal thresholds by invoking hotspots and self-focussing or reduced damping from non-Maxwell-Boltzmann distributions. On the other hand, "self-smoothing", nonlinear frequency shifts, secondary decay of Langmuir waves (Langmuir decay instability) or ion waves, and "self-induced" plasma inhomogeneity are invoked to explain the weak scaling above threshold. Using simple models of these effects in F3D, which naturally includes the self-focussing, self-smoothing, and self-induced inhomogeneity, we often find these nonlinearities are insufficient. We will present examples and argue that existing data is inadequate to guide the theory. Finally, we examine whether the existing laser facilities could provide such data.

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Poster

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# Direct drive pellet designs for the National Ignition Facility

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We have analyzed direct drive icf pellet designs for application to the 1.6 MJ glass laser National Ignition Facility (NIF). The primary tool for this analysis is the NRL FAST radiation-hydrocode; it runs in one to three dimensions, includes LTE & nonLTE multigroup radiation transport with an STA opacity database, and has fusion burn with multigroup alpha particle transport. The pellets under consideration for direct drive on NIF include the baseline all-DT design as well as one consisting of DT covered with a DT-impregnated low-density plastic foam. Designs exist for both the nominal and lower NIF drive energies. We present the details of these designs, their stability analysis, and fully integrated 2D simulations of the implosion, instability growth, and burn of the pellets. Of particular interest is the degradation of the pellet's yield as the initial asymmetries (e.g., laser imprint, surface finish, power balance) are varied.

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# Experimental studies of the effects of thin gold layers on the imprinting of laser nonuniformity onto plastic targets

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We present measurements of Rayleigh Taylor amplified laser imprint onto ablatively-accelerated plastic targets with and without thin gold layers using the Nike KrF laser facility. The laser pulse has a low-intensity 3 ns foot pulse followed by a 4 ns main pulse. The areal mass nonuniformity is measured by near monochromatic x-ray backlighting using streak and framing cameras. We find that with suitable choice of the gold thickness, the laser imprint can be substantially reduced, equivalent to more than a factor of 5 improvement in the uniformity of the laser illumination. The x-radiation from the gold layer during the foot pulse ablates additional plastic material and thereby greatly increases the separation between the laser absorption and ablation layers. The evolution of this long scale plasma is observed via side-on steak camera measurements of the x-ray emission from the targets. This long plasma would be expected to and apparently does substantially reduce laser imprint.

This work was supported by the U. S. department of Energy, Defense Programs.

# Modeling of KrF laser interaction with thin gold layers over plastic targets

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Improvements in the comparison between simulations of experiments of the interaction of NIKE with gold coated plastic targets and the experiments have been made. We present the results from modeling a series of experiments where a thin gold layer (100 Å- 400 Å) is deposited on top of a CH plastic target (around 40 $\mu$m). The NIKE laser pulse has typically a several ns (2-3), low-intensity (around a few $10^{12}$ W/cm$^2$) foot while the main pulse reaches $7 \times 10^{13}$ W/cm$^2$. In particular, the experiments show noticeable differences in the laser imprinting between the 100 Å gold layer case and the thicker layer (300-400 Å) cases. Also, many more X-rays are produced in the absence of a foot of the laser pulse.

An improvement to the non-LTE Busquet model has increased the emitted radiation in such a way that it allows us now to reproduce in a much better way these experimental features. Results from simulations will be shown, with the accent on the laser deposition and the radiation emitted respectively in the gold and the plastic of the target. Other detailed comparisons will be made as well as predictions for future experiments.

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Poster session preferred

# New/Old diagnostics: streak camera coupled with the high resolution x-ray crystal imager

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**Abstract**

The diagnostic setup is a modification of the Nike monochromatic x-ray imaging system based on the Bragg reflection from spherically curved crystals. An addition of a streak camera to this system makes it possible to analyze continuous time behavior of mass variation, which is necessary to reveal the non-monotonic evolution of the processes under study. The energy of 12 Nike beams, ~500 J, is delivered to a silicon backlighter target, producing x-rays that backlight the main target for about 5 ns. The spherically curved quartz crystal selects the resonance line of the He-like Si (1.86 keV) and projects a monochromatic image of the target on the slit of an x-ray streak camera. We use a quartz crystal with the cut 1011 and radius of curvature 200 mm. With magnification of 20 the crystal-to-detector distance is about 2 m. We are able to position the target image on the entrance slit of the streak camera with an accuracy that corresponds to 30 mm on the target. This setup provides spatial resolution in one relevant direction, e.g. along the wave vector of the ripple on the target surface, producing 1D streak records.

The spatial resolution of the x-ray optical system was tested with the help of x-ray film as a detector and was found to be of order 6-7 μm. High throughput of the x-ray optical system allows us to magnify the images by a factor of 20 to compensate for the modest resolution of the streak camera. Despite the high magnification of the system, the overall spatial resolution is still limited by the streak camera and was estimated by test pictures of the composite mesh. The MTF of the entire diagnostic system was obtained by imaging a knife-edge target and verified by imaging an undriven target with predetermined amplitude. The MTF at $\lambda$ =30 μm and 45 μm is 0.4 and 0.7, respectively. With 1.86 keV probing energy we were able to study 40 mm to 90 mm thick CH targets either flat or rippled with perturbation wavelength $\lambda$ = 30 μm or 45 μm. The streak records were taken with time resolution of 170 ps. This is sufficient for the 0.5 ns characteristic times of interest. The large field of view (500 μm) combined with the large flat top (400 μm) of the laser focal spot gives us more ripples available for Fourier transform analysis, thus ensuring confidence in determining the dominant mode's amplitude.

Work supported by the U. S. Department of Energy

Prefer Poster

# Direct observation of feedout-related areal mass oscillations in planar plastic targets

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## Abstract

"Feedout" means the transfer of mass perturbations from the rear to the front surface of a driven target. When a planar shock wave breaks out at a rippled rear surface of the target, a lateral pressure gradient drives sonic waves in a rippled rarefaction wave propagating back to the front surface. This process redistributes mass in the volume of the target, forming the feedout-generated seed for ablative Rayleigh-Taylor (RT) instability. The oscillations are expected if the perturbation wavelength $\lambda$ is not large compared to $2\pi L_s$, where $L_s$ is the shock-compressed target thickness. The oscillations change the phase of mass variation, making the target thicker where it was initially thinner. We report the first direct experimental observation of areal mass oscillation associated with feedout, followed by the onset of exponential RT growth. Our experiments were performed with the Nike KrF laser ($\lambda_L$ = 248 nm). The 4 ns long laser pulse was focused to a spot 750 μm in diameter FWHM, producing an intensity up to ~80 TW/cm$^2$. The mass redistribution in the target was observed with the aid of monochromatic x-ray imaging coupled to a streak camera. We used 40 μm to 60 μm thick CH targets rippled on the rear side with wavelengths of either 30 μm or 45 μm, the ratio $2\pi L_s / \lambda$ thus being close to 2. Two phase reversals of mass variation predicted by the theory and simulations were consistently observed both on the original images and on the time histories of Fourier amplitudes.

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Prefer Poster

# Direct observation of areal mass oscillations due to ablative Richtmyer-Meshkov instability in planar plastic targets

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## Abstract

The areal mass variation in a laser-driven target caused by either its surface roughness or by the imprint of the laser beam non-uniformity amplitudes, has been theoretically predicted to oscillate during the early shock-rarefaction transit time when the RT seeds are formed [1, 2]. The oscillations characteristic of the so-called ablative Richtmyer-Meshkov instability [2] have been reproduced in a number of simulations [3, 4] but never observed experimentally. The main problem associated with observing the ablative RM oscillations is their relatively low frequency, which is the reason why they have not been detected by the face-on measurements in earlier experiments [5]. Our experiments were performed with 4 ns long pulses of the Nike KrF laser using a novel diagnostic technique, monochromatic x-ray imaging coupled to a streak camera. A non-monotonic evolution of areal mass perturbations in an ablatively driven target during the shock-rarefaction transit has been observed for the first time. We used 40 μm to 90 μm thick CH targets rippled on the front side with perturbation wavelength $\lambda$ = 30 μm. This was short enough to make the oscillation half-period fit into the Nike pulse duration, but at the same time was resolvable by our diagnostics. We consistently observed the mass variation amplitude to grow, to reach a peak, and then to decrease due to the ablative RM instability, after which the exponential RT growth begins.

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Prefer Poster

# Numerical simulation of ablative Richtmyer-Meshkov instability and feed out experiments on the Nike laser facility

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## Abstract

In numerical simulations oscillations have been observed for some time in the amplitude of mass perturbations during the "foot" of pulses designed to compress and accelerate inertial confinement fusion pellets. These oscillations take place during the time of initial shock transit through the target until the rarefaction wave returns through the target. After the rarefaction wave reaches the laser side of the target, the target begins to accelerate leading to classical Rayleigh-Taylor instability growth. Detailed studies of this oscillating phenomena during the laser foot on planar targets has lead to an understanding of these oscillations in terms of the so-called ablative Richtmyer-Meshkov (RM) instability [1,2] driven by the "rocket effect" and the rear side feed out effect [3,4]. However previously the effect has never been observe experimentally. In this paper we will show the results of simulations of experiments carried out on the Nike laser facility that for the first time have experimentally observed this phenomena.

Simulations were carried out using the NRL FAST laser matter interaction code. Both single mode and multi mode simulations were carried out including the effect of residual nonuniformity from an ISI smoothed laser beam.

Work supported by the U.S. Department of Energy and ONR.

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prefer poster

# Absolutely calibrated, time resolved measurements of soft x-ray emission at the Nike laser facility

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## Abstract

The simulation of laser produced plasmas at the Nike is based of the FAST code suite that incorporates hydrodynamics, atomic physics, and radiation transport.[1] The Nike program has an ongoing experimental effort to test the predicted soft x-ray emission ($\lambda$ ~5 - 75 Å) from planar targets composed of a variety of materials (Au, W, CH, BN, Al, Kapton) and irradiated with a variety of laser irradiances ($10^{12}$-$10^{13}$ $Wcm^{-2}$). Results from an absolutely calibrated, time-resolving transmission grating spectrometer have shown promising agreement between theory and experiment at moderate spectral resolution ($\delta\lambda \sim$ 6.2 Å). These experimental data have been compared to the direct output of the 1-D non-LTE hydrodynamic simulation [2,3], i.e. the flux exiting the last cell (in planar geometry), resolved into photon groups. The experimental effort has begun to investigate the angular and spatial dependence of the emission. An additional transmission grating spectrometer and a new array of filtered diode modules are being prepared for a series of experiments to study the angular dependence of the soft x-ray emission. Preliminary investigations into the spatial dependence of the emission have used pinholes placed near the target to limit the spectrometer's field of view and have yielded insight into the expansion of the emission region.

Work supported by U. S. Department of Energy

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Prefer Poster Session

# Influence of Nonlinear Heat Conduction on Shock Waves in Spherical Explosions

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Following the work of Reinicke and Meyer-ter-Vehn,[1] we investigate the influence of nonlinear heat conduction on shock waves formed from strong point explosions. For this purpose, a one-dimensional, Eulerian, diffusive-hydrodynamic code has been written using an ideal gas equation of state, and a thermal conductivity modeled as a power law in temperature and density. In concert with the findings of Shestakov,[2] it is demonstrated that the time-dependent numerical solutions are characterized by both a shock and a nonlinear thermal wave. Although the coupled diffusive-hydrodynamic problem is not in general self-similar, the well-known Barenblatt[3] and Taylor-Sedov[4] results are limiting solutions that provide insight into the gas dynamical behavior at different stages of the simulation. At early times, the thermal wave dominates the hydrodynamic flow, and reduces the compression of the shock well below its classical value, while at late times, hydrodynamic-like behavior occurs. As shown by Reinicke and Meyer-ter-Vehn, a completely self-similar class of solutions to this problem also exists for particular choices of the thermal conductivity and ambient density profile, and this is confirmed by the simulations. In those cases, the thermal wave and shock evolve with the same time dependence, and for explosions that are sufficiently strong, a thermal front precedes an isothermal shock at all times.

The present work represents an initial investigation of the influence of nonlinear heat conduction on shock wave dynamics. The intent in the future is to extend the analysis to cases more directly relevant to inertial confinement fusion studies. These may include realistic equations of state, radiative and two-temperature effects, as well as systems in which the propagation of the spherical shock is not "free," but rather is supported by some sort of "piston," such as the plasma corona of a laser-irradiated target.[5]

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# WRMR Analysis: Wigner Function Representations of Multi-Resolution Analysis and its Applications in Plasma Physics

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WRMR analysis consists of a set of tools with which optimal wavelet families can be chosen for a variety of applications such as the numerical solution of nonlinear partial differential equations (PDE) and integro-differential equations (IDE), data compression, denoising, and pattern recognition. The Mathematica notebooks that can perform this analysis will be available on a laptop in order to demonstrate the performance of these filtering and data processing tasks. (Bring ascii files of your favorite (noisy?) data on a zip disk and maybe you'll get it WRMR analyzed on the spot!).

WRMR analysis combines Wigner phase space techniques with Multi-Resolution Decompositions (MRD) of a signal using Discrete Wavelet Transforms (DWT) as well as the 2D DWT MRD of Wigner phase space representations themselves. Techniques for making optimal wavelet choice emerge naturally from lowest level thresholding or largest coefficient thresholding of the MRD.

Examples will be given from simple signals, with or without noise, and real X-ray bolometry data from Z pinches. Wavelet based energy and power extraction schemes from very noisy data will be demonstrated.

Applications of WRMR analysis to the solution of nonlinear PDEs such as Burgers-KdV and NLS as well as the Vlasov-Poisson IDE system will be given.

*This work was sponsored by Sandia National Laboratories.

PREFER POSTER SESSION

P2-22

Title

# Dynamic material property measaurements with laser-launched flyer plates

Authors

D. C. Swift, D. L. Paisley, R. P. Johnson, R. A. Kopp, G. A. Kyrala
Los Alamos National Laboratory

Abstract

The Los Alamos Trident laser is used to launch one-dimensional flyer plates for impact on to target materials. Using line-imaging VISAR the flyer plate velocity, target free surface velocity and/or window interface velocities are recorded to determine the dynamic properties of various metals and alloys of interest. Large grain polycrystal and single crystal materials have been evaluated. The experimental techniques, initial data, and planned ICF materials will be discussed.

**Submitted to: Anomalous Absorption Conference 2001, Sedona, AZ for possible poster paper.**

# 31st Annual
# Anomalous Absorption Conference

## Wednesday, June 6, 2001

| | |
|---|---|
| 1:30 p.m. – 4:10 p.m. | Oral Session 3 |
| 4:10 p.m. – 5:00 p.m. | Lunch ? |
| 6:30 p.m. – 10:00 p.m. | Reception and Banquet |

# Compression Solutions for Backward Raman Amplification

V. M. Malkin, Yu. A. Tsidulko, and N. J. Fisch

One way to achieve pulse compression is by means of backward Raman scattering. To achieve the pulse compression effects at high power, the pump laser must be transported through transparent plasma. At high power, a properly formed seed pulse can completely deplete the pump, as the seed is both amplified and compressed. Moreover, the amplification process can outrun deleterious processes associated with the ultraintense pulse [1]. The mechanism of compression at high power is amplification of the pulse front sufficiently rapid to deplete the pump and thus shadow the trailing part of the pulse.

There are several effects that interfere with the process of amplification and compression. Even if the pump is transported through the plasma to the pulse without encountering deleterious instabilities itself, the amplified seed pulse can itself generate effects that interfere with its own compression. One concern is Raman forward scattering of a pulse undergoing rapid compression [2]. A second concern is that the pulse itself might generate non-compressing precursor pulses, that undergo some amplification but little compression. Precursors can then spoil the desired amplification process of the self-compressing signal pulse [3]. It turns out, however, that operation in a certain Raman detuning gradient creates favorable conditions for pulse compression, while suppressing both Raman forward scattering of the rapidly amplified pulse as well as the generation of precursor pulses.


1. V. M. Malkin, G. Shvets and N. J. Fisch, Fast compression of laser beams to highly overcritical powers, Physical Review Letters **82**, 4448 (1999).
2. V. M. Malkin, Y. Tsidulko, and N. J. Fisch, Stimulated Raman scattering of rapidly amplified short laser pulses, Physical Review Letters **85** No. 19, 4068 (2000).
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**Studies of High Energy Particle Generation and Energy Transport in Ultra-Intense Laser Plasma Interactions**

R. Kodama, K. A. Tanaka, Y. Kitagawa, H. Habara, Y. Sentoku, Y. Toyama, M. Tampo, T. Miyakoshi, F. Otani, T. Shozaki, K. Mima and T. Yamanaka

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We have studied ultra-intense laser plasma interactions related to the fast ignitor in inertial fusion energy. The interactions were investigated by using 50-100TW laser systems and particle-in-cell (PIC) simulation codes. Among the issues to be studied, we focused on the generation and transport of high energy density particles in the interactions as well as the laser beam behavior in long scale-length plasmas.

In the study of relativistic laser beam propagation in a 100-μm scale-length plasma, a special propagation mode (super-penetration mode) was observed, where the beam propagated into overdense regions close to solid target surface. At the super-penetration mode, 20% of the laser energy converted to energetic electrons toward the target inside while the coupling efficiency was 40% without the long scale-length plasmas.

High-energy ion generation was investigated with beam fusion neutrons from the target inside and with a variety of the target structures. The coupling efficiency from the laser to the high-energy ion was a few % at laser intensities of $10^{18\text{-}19}$W/cm$^2$. Wedge shape targets were used to study the ion generation mechanism changing the laser incidence angels. Focusing of the high-energy ions was also demonstrated with a cylindrical target, taking account of the ion generation.

Heating of solid targets by the high-density relativistic electros was also investigated with 2-dimensional UV images from the target rear side and thermal neutrons from the target inside. The images show the filament and channel of the electron heating in the solid targets. The temperature of the plasma heated by the energetic electrons was evaluated to be a few 100 eV. The number of filaments decreases with the laser energy, indicating the merge of filament with a magnetic field. The energy dependence implies pinch of the electron flow with a magnetic field induced by the spatially distributed conductivity of the electrons.

**Recent Activities on Fast Ignition Researches of Osaka University-enforced heating of highly compressed plasmas**

R. Kodama, K. Mima, A.E. Dangor*, H. Fujita*, H. Habara, Y. Izawa, Y. Kitagawa*, K. Krushelnick*, T. Norimatsu, P. Norreys**, T. Shozaki, K. Shigemori, A. Sunahara, K. A. Tanaka, Y. Toyama, M. Tampo, T. Miyakoshi, F. Otani, T. Yamanaka and M. Zepf*

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During the last several years, we have extensively studied elementary physics relevant to the fast ignitor in inertial confinement fusion. Laser-hole boring with enormous photon pressures into over-critical densities was experimentally proved by density measurements with XUV laser probing. In the study of relativistic laser beam propagation in a 100-μm scale-length plasma, a special propagation mode (super-penetration mode) was observed, where the beam propagated into overdense regions close to solid target surface. At the super-penetration mode, 20% of the laser energy converted to energetic electrons toward the target. Based on the investigation of the elementary physics, we are studying imploded plasma heating with 3 different approaches. One of the critical issues is how to inject the heating pulse to the high-density regions as close to the core plasma as possible. One approach is self-guiding of relativistic beam with the super-penetration mode and another the external solid cone guiding of the heating pulse to the core plasmas. The cone guiding approach removes the uncertainties and obstacles in the propagation physics except the implosion performance.

In the experiments of 100TW laser interactions with imploded plasmas with self-guiding approach, we obtained enhancement of the neutron yield. However, the most of the increase in the neutrons could be due to the beam fusion neutrons with accelerated ions in high-density region by the propagated laser beam. With the cone guiding approach, we obtained the first clear evidence of enforced heating of the compressed plasma as well as the demonstration of the cone attached shell implosion. We will discussed about the energy deposition rate of the relativistic electrons in high-density plasmas at $\rho r<0.3 g/cm^2$ from experiments. We will extend the discussion to the scheduled experiments on 1PW laser interactions with the compressed plasma in the near future as well as to the PW laser construction.

# Laser Self-Focusing in a Magnetized Plasma

C. Ren, Brian J. Duda, and W. B. Mori

University of California, Los Angeles

The propagation of high-intensity short-pulse lasers through plasmas has been studied extensively during the past few years for a variety reasons. However, almost all of this work assumed that the plasma was non-magnetized. We consider both analytically and in simulations how short-pulse lasers evolve in magnetized plasmas. Such work is of relevance to the fast igniter concept, the recently proposed Cherenkov wake concept, and the surfatron concept. We have initially concentrated on the nonlinear and finite spot size effects of the extraordinary mode (X-mode). The theory is based on the formalism developed by Dirac [1] and Duda [2], where the canonical momentum is written as $P+qA=\lambda\nabla\beta$. (This should be contrasted with the non-magnetized case where we have $P+qA=0$ with a proper choice of gauge.) For the resulting equations, a perturbation procedure is developed based on a small parameter $\varepsilon\equiv\omega_p/\omega_0$, the ratio of the plasma frequency to the light frequency. A single equation for the plasma transverse momentum is derived in a two dimensional slab geometry. The equation includes the nonlinear and finite spot size effects of the laser. As a first application of this equation, we study the self-focusing of the X-mode and find the power threshold for self-focusing is smaller than the non-magnetized case. Particle in cell simulations are also conducted to check the analytical results and to study the stability of X-waves in plasmas.

This work is supported by NSF Grant No. DMS 9722121 and DOE Contracts No. DE-FG03-98DP00211 and DE-FG03-92ER40727.

[1] P. A. M. Dirac, "A new classical theory of electrons. II", Proc. Roy. Soc., A **212**, 330 (1952).

[2] Brian J. Duda, PhD dissertation, UCLA (2000).

# Formation of Electromagnetic Post-Solitons in Plasmas

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With 2D3V Particle In Cell simulations we show that the electromagnetic relativistically strong solitons, formed in the wake of the laser pulse during the interaction of a high intensity ultra short laser pulse with a collisionless plasma, evolve asymptotically into post-solitons. A post soliton is a slowly expanding cavity in the ion and electron densities which traps electromagnetic energy. Fast ions are accelerated during the post-soliton formation. Post-solitons are elementary components of the relativistic electromagnetic turbulence in laser irradiated plasmas.

# A new mechanism for magnetic-field generation in collisional plasmas

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**Abstract**

Many magnetic-field generation mechanisms and instabilities in collisional plasmas are known to exist; e.g. the $\nabla T_e \times \nabla n_e$ source term and the thermomagnetic instability. The theories that describe these processes all use the local approximation (i.e. setting $f_o$, the isotropic part of the electron distribution, to a Maxwellian). It is well known that non-local effects are needed to properly describe heat flow down steep temperature gradients.

We show that non-local effects also play a role in magnetic-field generation in collisional plasmas. We find that spontaneous, large scale B-field growth is possible when $\nabla n_e = 0$, a situation where existing 'local theories' predict no growth, when non-local effects are taken into account.

Using a recently developed implicit 2D Fokker-Planck code (which self-consistently includes B-fields) we find that magnetic-fields can grow from nothing to values where $\omega\tau > 1$ (therefore significantly affecting transport) for non-uniform heating, even though $\nabla n_e = 0$.

Work supported by the EPSRC of the UK.

# X-ray radiation properties of different clusters under high-intensive fs laser interaction.

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Review of systematic investigations of X-ray radiation properties of different clusters heated by short-pulse high-intensive laser radiation will be presented. The cluster targets were formed by the adiabatic expansion in vacuum of an Ar and $CO_2$ gas puff produced by a pulsed valve with a Laval or conical nozzles. The gas jet pressure is varied from 15 up to 100 bar. The density of gas after the nozzle was characterized by interferometry. Detailed measurements of cluster parameters have been done by different methods and obtained data were compared with the theoretical modeling. For such modeling has been used so called moments method approach, which was developed and successfully used previously for modeling of wet water streams flows in nozzles and turbine cascades. Theoretical modeling included the two- phase gasdynamic processes in the nozzle forming jet and permitted to obtain the spatial distribution of cluster parameters in a gas jet, to take in the account the shape of nozzles and explain some experimental results.

Two sets of experiments, where different types of clusters were irradiated by short pulse (Ti:Sa lasers with energy 600 mJ, duration 60 fs and peak laser intensity $7\times10^{17}$ W/cm$^2$ and correspondingly, energy 15 mJ, duration 35 fs and peak laser intensity about $10^{17}$ W/cm$^2$) have been done. High spectrally ($\lambda/\delta\lambda$=2000-5000) and spatially (40-80 μm) resolved X-Ray spectra near resonance lines of H- and He-like ions of Oxygen and Ar have been obtained and detailed spectroscopic analysis was consistent with a theoretical two-temperature collisional-radiative model of irradiated atomic colusters incorporating with an effects of highly energetic electrons. The effect of fast electrons on the X-ray emission spectra of a femtosecond laser-produced-plasma that was created by the interaction of picosecond laser pre-pulse with clusters were considered. Comparison with data under various experimental conditions clearly demonstrated that for increasing X-ray output from plasma the most essential to increase size of clusters and at the same time increasing laser energy and flux density is not so important.

*This work was partly supported by the Fond Europeen de Developement Economique Regional and Conseil Regional d'Aquitaine, the U.S. Department of Energy and CRDF travel grant.

# Harmonics Generation in Super-Bright Laser Pulse Propagating through a Capillary.

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***and Sokolov, I.V.***

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As we reported before [1], in a super-bright laser pulse propagating through an empty capillary, with a density of the wall material being of the order of solid state density ($N_e \sim 10^{22}$ cm$^{-3}$), a resonant interaction between the subluminal motion of the pulse inside of the wave-guide (capillary), on one hand, and the relativistic motions of the charged particles in the relativistically strong pulse field, on the other hand, plays an important role.

Here we consider one more effect, which also results from the same resonant interaction – namely, the high frequency harmonics generation. In numerical simulations using the particle-in-cell method the main physical parameters were as follows. The electron density in the capillary walls related to the critical density for the pulse fundamental frequency was as high as $N_e / N_c = 8$. Although being supercritical for the fundamental pulse frequency, this density appears to be under-critical for the generated harmonics. The capillary cross section size was chosen to be slightly larger than the pulse half-wavelength, or, by the other words, the pulse frequency was barely above the cut-off frequency for the wave-guide. This was to slow down the pulse propagation and to facilitate its power conversion to the harmonics. The capillary walls were not too thick, up to 3-5 vacuum wavelengths, so that the harmonics could freely pass through the wall plasma without significant damping or changing the spectrum.

The results demonstrate a high efficiency of the pulse power conversion to high harmonics with the harmonics frequency being more than 10 times higher than the fundamental pulse frequency. As a confirmation of the resonance with the pulse group velocity, a typical bird-like spatial distribution of the electromagnetic energy formed, in which "the bird wings" outside the capillary showing the distribution of the harmonics energy move with the same velocity as "the bird body" inside the channel.

As the theoretical analysis shows, all the generated harmonics have rather narrow angular distribution of the wave vectors. The analogous problem for a plane plasma layer was solved in [2,3]. The angle between the direction of the harmonics propagation and the axis of channel is also governed by the resonance with the pulse propagation velocity.

References.

[1]. Sokolov, IV, Proc.30th Ann.Anom.Abs.Conf., Ocean City, (2000), p.303.

[2] Bulanov, SV, Naumova, N.M and Pegoraro, F. Phys.Plasmas, 1(3), 745, 1994

[3] Vshivkov, VA, Naumova, NM, Pegoraro F and Bulanov, SV. Phys.Plasmas, 5(7), 2727 (1998)

# 31st Annual
# Anomalous Absorption Conference

## Thursday, June 7, 2001

| | |
|---|---|
| **9:00 a.m. – 12:20 p.m.** | **Oral Session 4** |
| **12:20 p.m.** | **Lunch** |
| **7:30 p.m. – 8:30 p.m.** | **Confirmation Pending** |
| **8:30 p.m. – 11:00 p.m.** | **Poster Session 4** |

# Design of Long-Scale-Length Plasmas for Interaction Physics Experiments on OMEGA

R. S. Craxton, D. D. Meyerhofer, W. Seka, R. W. Short, and R. P. J. Town

LABORATORY FOR LASER ENERGETICS
University of Rochester, 250 East River Road, Rochester, NY 14623-1299

This paper describes the design of two long-scale-length plasma configurations used for recent interaction physics experiments on OMEGA. This work represents continuation of the program at LLE to replicate as closely as possible coronal plasma conditions anticipated during various portions of the baseline NIF direct-drive laser pulse.

The first plasma is designed to enhance stimulated Brillouin backscattering by generating regions of low velocity gradient. A solid CH target is irradiated first by nine OMEGA beams at 62° incidence, to form a plasma, and then by seven beams at angles from 23° to 48° that serve to maintain the plasma temperature. A single interaction beam at normal incidence is coincident with the second set of beams. All beams have a temporal shape whose rise is approximately linear over 2 ns. The ablation of fresh plasma due to the rapidly rising interaction beam results in a flatter, and sometimes reversed, velocity gradient in the corona. This behavior is similar to that found in simulations of NIF direct-drive targets just after the end of the "foot," when the laser pulse rises rapidly.

The second plasma is designed to look at the effects of multiple, overlapping interaction beams. Here all laser pulses are approximately flat with ~1-ns duration. The plasma is formed by nine beams at 62° incidence followed by six beams at 48°. Up to six interaction beams follow in a ring at 23°. The temporal separation of the plasma-forming and interaction beams eliminates the possibility of scattered light from the plasma-forming beams affecting streaked backscatter measurements of the light from the interaction beams. The plasma conditions may be varied by changing either the number or the focal diameter of the interaction beams.

The experimental results and theoretical interpretation are reported in subsequent papers.[1,2]

1. W. Seka *et al.*, this meeting
2. R. W. Short *et al.*, this meeting

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

Prefer oral presentation. We would appreciate placement of our three papers on this topic in the order Craxton, Seka, Short.

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# Multibeam SBS Interaction Experiments in OMEGA Long-Scale-Length Plasmas

W. Seka, S. P. Regan, D. D. Meyerhofer, B. Yaakobi, C. Stoeckl, R. S. Craxton, and R. W. Short

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H. Baldis
ILSA, Lawrence Livermore Laboratory, Livermore, CA.,

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A series of long-scale-length interaction experiments on OMEGA concentrated on multibeam SBS interaction processes under NIF direct-drive plasma conditions. The experiments used two sets of plasma-creating beams over 2.5 ns. A third set of six beams was used as interaction beams. These beams were delayed by another nanosecond and were arranged symmetrically at ~20° around the target normal. The targets were thick plastic and the typical plasma scale lengths were predicted to be several hundred microns with temperatures ($T_e$) in the 2- to 3-keV range. Two-dimensional smoothing by spectral dispersion (2-D SSD) at 1 THz and polarization smoothing were employed on all beams. Peak single-interaction-beam intensities ranged up to $10^{15}$ W/cm$^2$ (averaged over the speckle pattern).

The SBS backscatter signals were obtained through the *f*/6 focusing lenses in two beams with time-resolved spectra and calorimetric measurements. No measurements have as yet been made outside the lens cone. The overall SBS reflectivity due to the multibeam interactions is almost an order of magnitude higher than is observed in single-beam-interaction experiments. At high intensities the multibeam SBS backscatter levels saturated in the 1% to 5% range. The SBS observations indicate that seeding by electromagnetic radiation is of primary importance. The seeds are provided by the various interaction beams that are diffusely or specularly reflected near the critical density. By far the most effective seeding is due to specular reflection of the seed waves. In contrast, common ion waves driven by the symmetrically arrayed interaction beams are of secondary (if any) importance. Within the intensity range of NIF direct-drive ignition experiments, the multibeam backscatter levels were well below 1%.

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

Prefer oral session

# Theoretical Interpretation of SBS Observations in OMEGA Long-Scale-Length Plasma Experiments

R. W. Short, R. S. Craxton, W. Seka, and D. D. Meyerhofer

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Recent experiments on OMEGA have studied stimulated Brillouin backscatter in long-scale-length plasmas under a variety of irradiation conditions, measuring scattered light intensities and spectra. Ion Landau damping is estimated to be sufficiently strong in these plasmas that the locally driven approximation for the ion-sound wave can be applied. The linear SBS gain coefficient can then be obtained by integrating the coupled wave equations for the incident and scattered light throughout the underdense plasma corona. Using density, velocity, and temperature profiles obtained from the two-dimensional Eulerian hydro code *SAGE*, we have calculated as a function of wavelength the SBS gain coefficients to be expected in these experiments. Comparison with the observed scattering levels and spectra allows several conclusions to be drawn regarding the SBS process in these plasmas:

1. The scattering appears to be dominated by SBS occurring in hot spots.

2. Consequently, since hot spots from distinct beams seldom overlap, most SBS is expected to be driven by individual beams rather than resulting from a multi-pump process. This conclusion is supported by the results of experiments with multiple beams.

3. The plasma profiles obtained from *SAGE* give good fits to blue-shifted SBS emission originating in the outer corona, but scattered light originating near critical density shows unexpectedly large values of absorption and spectral red shift.

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

Prefer oral session

# Measurements on the Two-Plasmon-Decay Instability on OMEGA

C. Stoeckl, R. E. Bahr, V. Yu. Glebov, D. D. Meyerhofer, W. Seka, R. W. Short, and B. Yaakobi

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The two-plasmon decay (TPD) instability is the predominant mechanism to produce suprathermal electrons in direct-drive experiments on OMEGA. These energetic electrons preheat the fuel and may prevent the requisite conditions for ignition in inertial confinement fusion from being reached.

TPD has an optical signature at $3\,\omega/2$ of the incident laser, which can be correlated to the hard x-ray radiation generated by the interaction of the hot electrons with the target. Operating both a time-resolved $3\omega/2$ spectrometer and a time-resolved hard x-ray detector on a variety of planar and spherical experiments on OMEGA has yielded an extensive database of measurements that can be used to improve the understanding of the TPD instability.

In spherical experiments the $3\omega/2$ emission, correlates very well both in time and power with the hard x-ray radiation and shows similar scaling with intensity. In planar experiments the correlation is not as favorable, most probably because of the dependence of the $3\omega/2$ signal on the observation angle. A first attempt to absolutely calibrate the hard x-ray detector using $K_{\alpha}$ radiation from embedded Ti and V layers will be presented.

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

Prefer oral session

$31^{st}$ Annual Anomalous Absorption Conference
Hilton Sedona Resort, Sedona, Arizona
3-8 June, 2001

# Optical Mixing Controlled Stimulated Scattering Instabilities in Beryllium targets: The Weak Ion Acoustic Wave Damping Regime

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We report on experiments conducted on the Omega laser facility at LLE using Beryllium (Be) exploding foil targets. In these experiments, we measured the effects of a large amplitude ion acoustic wave (IAW), generated by the optical mixing of two counter-propagating high intensity laser beams, a pump and a probe, on the stimulated Raman and Brillouin backscattering of the pump (SRBS and SBBS, respectively). We report the first incident of over a hundred percent probe energy transmission measured in large scale laser-plasma interaction experiments due to optical mixing generated IAWs. Since more energy comes out of the plasma than went into the probe beam at the entrance and since absorption is around 40 %, we conclude that energy transfer must have occurred from the pump to the probe beam. We were unable to detect significant SBBS in these Be plasmas, however.
Detailed analysis of the temporally and spectrally resolved SRBS data and the transmission of the probe beam reveal that there are specific temporal and spectral (which translates to specific density or spatial) windows in which the backscattering reflectivities are most significantly reduced, as would be expected in these inhomogeneous flowing plasmas. We will show results when the lasers were focused and pointed at the Mach -1 surface and compare cases where the ratio of the probe to pump intensities is $1/10:1, 3/4:1$ and $1:1$. We will contrast these $5\mu m$ Be exploding foil target results with our previous CH data with $10\mu m$ foils which are very similar hydrodynamically but in the strong IAW damping regime.

Our long term goal is to find efficient ways to generate large enough (EPW and IAW) disturbances in the plasma so as to control backscattering levels of SRS and SBS in targeted regions of large scale plasma.

*This work was performed under the auspices of the U. S. Department of Energy under the grant DE-FG03-99SF21787. LANL and NRL staff acknowledge the support of their respective laboratories and their DOE contracts. The work of LLE employees was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC03-92SF19460 and the University of Rochester. The work by LLNL employees was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-ENG-48.

PREFER ORAL SESSION

# Influence of the Langmuir decay instability on the saturation of stimulated Raman scattering.

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The occurrence of the Langmuir decay instability (LDI) of electron plasma waves (EPW) driven by the stimulated Raman scattering (SRS) has been demonstrated experimentally via the direct observation of the two products of the instability, namely the secondary ion acoustic waves (IAW) and EPW [1]. The Thomson scattering diagnostics used for this observation allow the clear identification of the waves through the measurement of their spectral features. It also yields the respective level of the wave amplitudes showing their strong correlation .

An interpretation of this experimental observation has been proposed which is based on the absolute growth of the Raman instability in a parabolic density profile resulting from the self-focusing of the interaction beam inside speckles [2]. We will present further results which support the strong influence of self-focusing in our experiment. The stimulated Raman and Brillouin scattering reflectivities are indeed measured to depend mainly on the power contained inside one speckle whereas a strong reduction [3] of these two instabilities is observed when adding polarization smoothing on the interaction beam.

Several experimental configurations such as polarization smoothing and/or beam crossing have been used that provide further elements for studying the influence of the Langmuir decay instability on the saturation of SRS. The corresponding experimental results will be presented.

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# Recent Trident Single Hot Spot Experiments: Evidence for kinetic effects, and observation of LDI cascade

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Experiments in the single hot spot regime have been recently performed on the Los Alamos Trident laser. The experiments have focused on the following issues. First, the intensity scaling of SRS for classically large damping regimes ($k\lambda_D \approx 0.35$) was examined, and compared to classical SRS theory. We find the SRS onset at intensities much lower than expected, from which we infer non-classical damping. Second, we examined the backscattered spectrum and observed scattering from a plasma wave whose frequency and phase velocity are between an ion acoustic wave and electron plasma wave. The presence of this wave cannot be explained by linear Landau theory, and we show that it is consistent with a BGK-like mode due to electron trapping. Finally, we used Thomson scattering to probe the plasma waves driven by SRS, and have observed structure consistent with multiple steps of the Langmuir decay instability. The details of these experiments and our analysis will be presented in various posters at this conference.

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# Damping Rate for Weakly Perturbed Large Amplitude BGK Modes

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The Landau contour recipe, and associated damping rate[1], $\gamma_L$, provide a simple closed form solution for the decay of a *freely propagating, infinitessimal amplitude* plasma wave (PW). *Finite amplitude* propagating solutions of the Vlasov-Poisson equation, BGK[2] modes, when perturbed by weak collisional damping, $\nu$, were found by Zakharov and Karpman[3] to decay at a rate which varies as $\gamma_L \nu/\omega_b$, where $\omega_b$ is the electron bounce frequency.

For the case of weakly driven PWs, whose electrostatic potential amplitude, $\phi$, is determined by a balance between a source, *e.g.*, the injection of Langmuir waves by SRS, and the slow escape rate, $\nu$, of trapped particles, I have calculated the first two terms in the perturbative expansion of the imaginary part of the nonlinear PW susceptibility, $\Xi$. At resonance, it determines $\phi$. These two terms are both proportional to $\nu$, with the first varying as $\gamma_L/\omega_b$, as in the Zakharov-Karpman result, and the next (second) order term, $\delta\Xi_2$, is $\phi$ independent.

$\delta\Xi_2$ is a smooth integral function of the background distribution function, $f_0$, and does not display the sensitivity to minute variations of $f_0$, as does $\gamma_L$, which depends on $f_0'(\mathrm{v})$. For large $\mathrm{v}/\mathrm{v}_e$, on the Bohm-Gross branch[4] of the electron PW nonlinear dispersion relation, it only varies algebraically, instead of the super-exponential behavior of Landau damping, so that for modest $\phi$, $\delta\Xi_2$, quickly dominates as the PW phase velocity, v, increases beyond a few electron thermal speeds, $\mathrm{v}_e$. For v of the order of $\mathrm{v}_e$, the electron acoustic branch of the BGK mode[5], $\delta\Xi_2$ is typically small compared to the first order term and is not of practical significance. Nevertheless it is interesting to note that for the case of Maxwellian $f_0$, it goes through zero at about $\mathrm{v}/\mathrm{v}_e$=2.1, and lowers the total damping below the first order term, for smaller v.

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# Laser-Plasma Interactions in Reduced-Scale Halfraums*

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Reduced scale (Nova scale 1/2 – 1/4, 800 μm and 400 μm diameters, respectively) halfraum targets have been designed for and fielded on the Omega laser at the Laboratory for Laser Energetics (LLE), with future shots scheduled for later this year. Approximately 10 TW of power is incident upon these targets, distributed among three beam cones, each with a spot size of about 80 μm. This provides interactions at moderately high intensities, in excess of 1 x $10^{16}$ W/cm$^2$. These targets are predicted to have a high radiation temperature (300 –390 eV), high electron temperature (10 – 20 keV), and exhibit halfraum filling on the time scale of the pulse length (~ 1 ns). To achieve the radiation temperatures indicated in Lasnex simulations, it is necessary to control the laser-plasma interactions in these targets.

Fluid simulations performed with pF3d of the laser beam propagating through plasma conditions such as those found around the laser entrance hole (LEH) of reduced-scale halfraums result in significant filamentation, and experimental backscatter spectra demonstrate that backscatter is not negligible. Fluid and particle-in-cell (PIC) simulations as well as experimental backscattter data will be presented and discussed.

Prefer Oral Session

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## Poster Session 4

## Thursday, June 7, 2001

## 8:30 – 11:00 p.m.

31st Annual Anomalous Absorption Conference
Sedona, Arizona
4-8 June, 2001

# Laser-plasma interactions in overlapping laser beams*

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ICF laser systems deploy ever larger numbers of beams that overlap at the absorption region in direct drive, or overlap in a volume such as the laser entrance hole in indirect drive. To first approximation, we usually consider the filamentation and scattering of the beams to be independent, (although for NIF we model the four ~f/20 beams of a NIF "quad" as one ~f/8 beam). Interactions between beams is an ongoing topic of research at most laboratories. Here, we extend our recent modeling of power transfer between beams to include additional effects.

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# Heat transport and electron distribution function in laser produced plasmas heated by localized hot spots

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The evolution of a collisional plasma which is heated by single or multiple localized laser hot spots is studied using Fokker-Planck (FP) and particle-in-cell (PIC) simulations. For small laser intensities good agreement is found with a nonlocal linear theory of plasma hydrodynamics [V. Yu. Bychenkov *et al.*, Phys. Rev. Lett. **75**, 4405 (1995)]. This theory for nonlocal thermal transport is generalized for large temperature perturbations leading to a practical expression for the nonlinear nonlocal heat flux which is in good agreement with results of FP and PIC simulations.

The electron distribution function (EDF) has been analyzed at different spatial locations with respect to the localized heating source. The EDF is dependent on the interplay between inverse bremsstrahlung heating and nonlocal transport. We have found significant high-energy tails of the EDF which have power dependence. An analytical theory based on the self-similar solution to the kinetic equation is able to explain such a behavior of EDF. High-energy electron tails may have strong impact on the excitation of parametric instabilities in nonuniformly heated laser plasma.

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# Nonlinear evolution of laser filaments in plasmas

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The nonlinear evolution of ponderomotive laser filaments is studied in three spatial dimensions by means of numerical simulations and theoretical modeling. Numerical simulations are performed using codes with paraxial and non-paraxial models for light propagation. The scenarios of hot spot evolution strongly depend on the ratio of power in a hot spot $P$ to critical power $P_{cr}$ as well as on the ratio of the plasma density $n_e$ to the critical density $n_{cr}$ and on the incident light f-number $f$ (cf. [1]).

In the range of parameters where $P/P_{cr}$ does not exceed 10, the following three different scenarios of hot spot evolution are identified :
1) Small $P/P_{cr} \leq 1$. Formation of a quasi-stationary hot spot.
2) $P/P_{cr} \sim 1$. Non-stationary decay of a hot spot into two hot spots.
3) Large $P/P_{cr} \gg 1$. Resonant instability of a nonlinear filament [2], followed by highly nonstationary behavior of laser intensity and plasma density. The instability does not affect a tightly focused hot spot at the front of density channel, which remains stationary during the destruction of nonlinear filaments.

Results of numerical simulations are compared with theoretical calculations, based on the Schrödinger equation for localized modes in realistic density channels. The appearance of a second trapped mode is used to identify a resonant instability in the nonlinear evolution of filaments.

The angular and frequency spread of light at late stages of filament evolution are calculated. The influence of this additional temporal and spatial light incoherence on the plasma-induced laser smoothing effect [3] is demonstrated.

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# A kinetic $\delta f$ Model of Plasma and Acoustic Waves which includes an evolving Background Distribution – Extension to two Spatial Dimensions[1]

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The augmented $\delta f$ algorithm developed for the study of long-wavelength plasma and acoustic waves and previously demonstrated in one spatial and one velocity dimension[†] has been implemented in two+two dimensions. The method consists of solving the collisionless kinetic equation for the small deviation $\delta f = f - f_0$ of the full distribution $f$ from a large lowest order $f_0(\vec{x}, \vec{v}, t)$ which is parameterized in terms of a velocity $\vec{u}(\vec{x}, t)$ and a tensor $\vec{\vec{a}}(\vec{x}, t)$, each satisfying a nonlinear fluid equation. Specifically, $f_0 = f_0(\vec{w} \cdot \vec{\vec{a}} \cdot \vec{w})$, where $\vec{w} \equiv \vec{v} - \vec{u}$. With this representation, the source $-df_0/dt$ for the evolution of $\delta f$ along the phase space characteristics is reduced to order $((|\vec{k}|w/\omega)^3$, for waves of frequency $\omega$ and wavevector $\vec{k}$. This reduction enables efficient, low noise simulations which require relatively few marker particles to represent $\delta f$. Comparison with full PIC and with $\delta f$ simulations which do not evolve $f_0$ will be presented.

†E. Valeo, S. Brunner and J. A. Krommes, $4^{th}$ International Workshop on Laser-Plasma Interaction Physics, Banff, Alberta, CA, 21-24 February, 2001, paper THE1.

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# Velocity Distribution Functions in Laser Hot Spots

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This work is part of an ongoing effort in combining transport and microinstability simulations[1] under conditions similar to single laser hot spot experiments[2]. Fokker-Planck calculations of the non-classical drive and transport, arising under such conditions, are carried out in the attempt to provide realistic velocity distribution functions (VDFs) to the subsequent Stimulated Raman Scattering (SRS) simulations.

The Landau damping rates, and therefore the thresholds of SRS are very sensitive to the shape of the tails of the VDFs[3]. Spatial transport can thus play an important role in this context as these tails are formed by the highly mobile (long mean free path) particles. Under conditions of the single laser hot spot experiments, where the temperature variation is modest, the full Fokker-Planck simulations indeed predict that these tails remain essentially Maxwellian – from the surrounding thermalized plasma up to the very center of the hot spot – instead of the strongly depleted, super-Gaussian tails predicted by a local (neglecting transport) calculation[4]. However, our results also show how this situation may change in the presence of many such hot spots, where the stronger drive leads to a large temperature increase. In this case, the tails remain nearer to super-Gaussian.

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# Direct specroscopic observation of ions acceleration in $CO_2$ laser produced plasma.

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The acceleration dynamics of aluminum plasma produced by radiation of $CO_2$ laser was studied by combination of space-resolved X-ray spectral measurements and the time-of-flight technique. Soft X radiation was recorded by spectrographs with spherically curved mica crystals. The mica crystals, plasma, and a film were arranged according to the FSSR-1D scheme[1]. The electrostatic ion analyzer 3 meters distant from the target was used to measure ion energy distribution. High spectral and spatial resolution of the X-ray spectrographs allowed us to derive from densitograms of He-like resonant lines an ion velocity dependence on the distance from the target in the range 0 - 2 mm. In spite of the fact that measurements were made at very moderate laser intensity of $6 \cdot 10^{12}$ W/cm$^2$ both diagnostics registered ions up to energy of 1 MeV and even more.

To reveal the physical pattern of the plasma ionization and expansion we performed numerical simulation using codes GIDRA-1D and GIDRA-2D. Physical model is described in detail in the work[2]. The codes solve equations of plasma hydrodynamics and population kinetics. Two-dimensional simulations have demonstrated that at the time of peak of laser power radiation is additionally focused in the plasma corona due to refraction. This additional focusing leads to about two orders of magnitude higher laser intensity in the central region of the focal spot. Laser light pressure creates cavity in the spatial plasma density profile and provides additional acceleration to plasma. Good correlation of experimental values of plasma velocity values and those obtained by 2D simulation was obtained only when laser pressure was included.

Two-dimensional modeling impose restrictions on the size of numerical mesh. The spatial resolution of a mesh in 2D simulations was not sufficient to calculate correct line profiles because of very small doppler widths of spectral lines (low ion temperature in the corona). 1D simulations made on fine mesh allowed to reproduce experimental line profiles provided electron heat flux limiter was set to rather small value of f=0.02. Nevertheless, maximal ion energies registered by time-of-flight diagnostics were not obtained neither in 1D nor in 2D simulations. The additional acceleration on the front of expanding plasma ions could acquire due to electrical field arising due to escape of fast electron from the plasma volume.

AYF and TAP appreciated CRDF Travel Grant Program for the possibility to present this report at the Conference.

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# About a role of resonant absorption of laser radiation at generation of fast ions in $CO_2$-laser-produced plasma.

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The investigations of fast particle production in laser plasma is actual not only for fundamental understanding of the physical processes occurring in high-temperature plasma, but also for solution of a number of the important applied tasks, such as creation of injectors of multiply charged ions for heavy ion accelerators or laser thermonuclear fusion. Note that in the last case the presence of fast particles can play both a negative role (preliminary warm -up of a spherical target and decreasing of its compression) and positive one (ignition of thermonuclear reactions.

The experimental and theoretical researches which have been carried out for last 30 years, have shown, that the main parameter defining physics of generation of fast particles in laser plasma, is the product $q_{las}\lambda_{las}^2$, where $q_{las}$ and $\lambda_{las}$ – flux density and wavelength of laser radiation. Obviously, that one this parameter can not describe all features of the physical processes resulting in to acceleration of electrons and ions, and in various experimental conditions even at fixed value of the parameter $q_{las}\lambda_{las}^2$ the efficiency of fast particle production may be different. For example, the efficiency of mechanisms of acceleration must depend on duration of laser pulse (especially, in case of ultra short laser pulses) or on the state of substance of a target (solid, gas, and clusters). The experimental researches carried out in the present work, have shown, that there is one more rather not apparent parameter defining an amount of generated fast particles. Namely, this parameter is a relative aperture of an objective used for focusing of laser radiation, or, more precisely, ratio of a diameter of a laser beam $D_{las}$ to a focal length F of an objective.

The present experiments carried out in TRINITI on the powerful $CO_2$-laser installation TIR-1 show that, the number of fast ions grows at increase of the parameter $D_{las}/F$. The theoretical consideration carried out in the present work has allowed to explain this effect. It is shown that it is caused by the resonant absorption of a laser photons incident on a target not on a normal to a surface. The good agreement between the experimental and theoretical results has been obtained.

AYF and TAP appreciated CRDF Travel Grant Program for financial support to present results of report at the Conference.

# Braiding of Two Spiraling Laser Beams due to Plasma Wave Wakes

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Recently we studied how two lasers can mutually attract each other in a plasma via the relativistic nonlinearity. Such a nonlinearity is instantaneous so that each cross section of the beam behaves independently. Such an attraction was verified using the 3D PIC code OSIRIS. However, the simulations also showed that the lasers intertwine or become braided. To understand the braiding we have extended the theory to include a non-instantaneous nonlinearity, where the nonlinear coupling at a certain position depends on not only the local field intensity but also the intensity of the laser beam in front of it Using a variational principle, we derive equations of motion for the centroid of each beam under the interaction of the mutually excited plasma wave wakes. We find such a nonlinearity leads to braided solutions. The results developed here can be generalized to other nonlinear optical media with non-instantaneous nonlinearity.

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**A variational approach to coupling between forward Brillouin scattering and self-focusing**

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The evolution and stability of single speckles in long scale-length plasma is of interest to ICF applications [1,2]. In this paper, we use a variational principle approach [3] to study the evolution of a single isolated speckle. We start from the coupled equations between the laser and the ion acoustic wave. An action is derived whose Euler-Lagrange equations recover the starting equations. A trial function which parametrizes the speckle in terms of a spot-size, centroid position, amplitude, phase velocity, etc. is inserted into the action and the integration in the transverse direction is performed. Requiring that this action be stationary gives envelope equations for the trial function parameters. Using this approach we will provide growth rates for spot-size self-modulation and hosing instabilities which couple the forward Brillouin Scattering and self-focusing instabilities. It is found that for physical regimes achievable in laboratory settings, the wave-number for which the instabilities achieve peak growth is on the scale of the Inverse Rayleigh Length $x_R^{-1}$, rather than the ion-acoustic frequency, $c_s/w_0$, where $w_0$ is the spot-size of the pump and $c_s$ is the sound speed. Similarities and differences between this approach and that in ref. [2] will be discussed. Preliminary results on studying the stablitity of a single speckle using F3D will be presented as well as directions for future work will also be given.

Work supported by grants DOE DE-FG03-98DP00211, DOE DE-FG03-92ER40727, NSF DMS-9722121, and LLNL W-7405-ENG-48.

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Hilton Sedona Resort, Sedona, Arizona

**Collisional effects on intense electron beam propagation in plasmas and their relevance ot the fast ignitor concept**

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Transport of electron beams in plasmas is a fundamental issue in laboratory and astrophysical plasmas. For sufficiently cold beams, a significant amount of free energy of the beam can be transferred to the magnetic field through the Weibel instability, leading to a reduction of the energy transport along the initial beam direction. We have performed 2D and 3D PIC simulations for parameters relevantt to the fast ignitor concept, and we have analyzed the role and interplay of the Weibel instability and the two stream instability in this context. While in 2D the saturated state reveals the presence of large stable current filaments, in the 3D runs the small scale filaments are tilted, and break up along the propagation direction. This severely limits the coalescence of filaments and results in beam spraying. Our results show significant differences between the 2D and 3D simulations.

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# Simulations of Pulse Compression and Amplification in a Plasma

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Power limitations in short pulse laser systems are generally due to the damage threshold of the gratings used in the process of chirped pulse amplification. It has been proposed that such limitations might be overcome by using plasma as the amplifying medium [1-3]. In such schemes, a short seed pulse gains energy from a counterpropagating pump via the Raman instability. Fully nonlinear fluid simulations confirm earlier predictions that substantial compression and amplification can be obtained, even though the plasma wave acquires significant harmonic content. Particle-in-cell simulations show that the intensity of the amplified pulse is limited by wavebreaking to a quiver velocity of about half the speed of light. Simulations of recent experiments will be presented.

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Poster

# Portable, tunable, high-luminosity spherical crystal spectrometers with X-Ray CCD or MCP for high-resolution X-Ray spectromicroscopy of fs laser-produced plasmas.

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Investigations of X-ray radiative properties of different plasma sources is one of the key elements of plasma diagnostics nowadays. Important information about spatial distribution of electron and ion temperature and density, generation of fast ions and hot electrons could be obtained by applying high-resolution X-ray spectromicroscopy methods for plasma diagnostics. But successful using such methods is impossible without developing X-ray spectrometers, which have not only high sensitivity, but allow to obtained X-ray spectra simultaneously with high spectral and spatial resolution.

In this report we present first results of fs laser-produced plasma diagnostics, which were obtained by using Focusing Spectrometer with Spatial Resolution (FSSR- spectrometer) having as an X-ray detector Princeton X-ray CCD or Hamamatsu X-ray MCP. A portable (200x100x100 $mm^3$), high-luminosity spherically bent crystal spectrometer was designed for the purposes of measuring in wide spectral range 1.2-19.6 very low emissivity X-Ray spectra of different targets, heated by fs laser radiation, with simultaneously high spectral ($\lambda/\delta\lambda \sim 1000$-5000) and space (40-200 μm) resolution. Large open aperture mica spherically bent crystals (30x10 $mm^2$ and 50x15 $mm^2$ with R=100 and 150 mm, correspondingly) are used as a disperisve element of spectrometer.

High spectrometer tunability allowed to receive high-resolved spectra of clusters, heated by 35 fs Ti:Sa laser pulses with energy only 15 mJ in spectral ranges: 15 - 17 - for H- and He-like ions of Oxygen ($CO_2$ clusters), 5 - 5.7 - for Ne-like like ions spectra of Kr, 3.0 - 3.4 and 3.7 - 4.4 - for H- and He-like spectra of Ar without any realignment of X-ray CCD spectrometer during one set up. Using another set up of spectrometer with X-Ray MCP in one alignment have been received spectra of solid targets, heated by 60 fs Ti:Sa laser pulses in spectral ranges: 15.2-17.5° - near resonance lines of He-like ion of Fluorine ($CF_2$ and $CaF_2$ targets), 7.6- 8.75 - for spectra between $He_\alpha$ and $K_\alpha$ lines of Al and near Rydberg lines of Ne-like Cu, 3.04 - 3.5 - for spectra around $K_\alpha$ lines of Ca ($CaF_2$ target), 1.38 - 1.59 - for spectra around $K_\alpha$ lines of Cu.

Thanks to the high sensitivity (high collection efficiency) of the spectrometer with MCP, high quality spectrally resolved images of Fluorine and Al could be obtained only in 1 shot of Ti:Sa laser with energy of laser pulse about 600 mJ and pulse duration 60 fs or for energy 300 mJ and pulse duration 8 ns. Some results of plasma diagnostics for both cases of clusters and solid targets, heated by fs laser radiation will be presented and discussed.

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# DIRECT EXPERIMENTAL DETERMINATION OF SPATIAL TEMPERATURE, DENSITY, AND MIX FOR LTE IMPLOSIONS

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Advances in diagnostics development and related image analysis procedures are enabling a more fundamental understanding of LTE implosions than previously possible. The most conceptually direct diagnostics suite utilizes a gated monochromatic imager (GMXI); streaked spectrometer; and an absolutely calibrated, time-integrated spectrograph. Although spectrometers are used, the imaged capsules should be in LTE, normally viewing continuum emission. The GMXI should be run in 2-color mode (for T and rho only), or 3-color mode (including mix). Data analysis involves two other inputs; an opacity at the two or more colors; and the degree of absorption of the emitting region by relatively cold blowoff material. The latter can be approximately obtained either from simulations, or from monochromatic detection of backlit imaging. The key concept is that the number of unknowns should equal the number of quantities measured. The unknowns are extracted by linearizing the LOS equation and iterating a multi-variable Newton procedure to convergence. We will present a detailed sensitivity and uncertainty analysis of diagnostic-related quantities by generating synthetic images from RadHydro simulations, passing these images thru the data-analysis algorithm, and comparing output unknowns with the simulation results. A substantial portion of the analysis will focus on the importance and uncertainty of absorption by the cold material, and of ways of alleviating the importance of this input.

# Line Emission as a Function of Surface Roughness in 2D and 3D Simulations

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ICF capsules suffer degraded performance due to the growth of perturbations on the capsule surface during an implosion. Line emission from argon placed in the fuel and titanium placed in the inner portions of the plastic shell can be used as a diagnostic of the amount of perturbation growth. In this paper, we model the implosion of indirectly driven ICF capsules in two dimensions with Lasnex and in three dimensions with HYDRA. The temperature and density from the radiation-hydrodynamics simulation (2D or 3D) is used as input to Cretin, which computes the line emission.

This paper reports on the results of our first attempt to study the dependence of the line emission on the initial surface roughness of the capsule in 3D models. The drive radiation is assumed to be perfectly uniform and the perturbation is placed only on the outer surface of the capsule. The capsule and drive radiation are characteristic of experiments performed on NOVA several years ago. We compare the results to 2D models and to experimental data.

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

# DIRECT NUMERICAL CALCULATION OF X-RAY AND NEUTRON IMAGING USING APERTURES

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The ICF program makes extensive use of x-ray imaging utilizing apertures. Pinhole, penumbral aperture, and ring aperture imaging have all been demonstrated. [1,2,3] Pinhole and penumbral aperture neutron imaging are currently being developed for applications to National Ignition Facility and Laser Megajoule experiments. [4,5]

Previous analysis techniques have used approximations based on Fourier transforms to reconstruct a source from the measured image. We proceed in a more straightforward manner: direct integration of the probability distribution over the areas of the square pixels followed by matrix inversion. For neutron imaging, penetration of and scattering within the aperture substrate are explicitly calculated. Discretization of the source and neglect of multiple scattering are the only approximations made.

This method offers a number of important advantages over other techniques. Consideration of noise and matrix conditioning allow the determination of optimal choices for the pixel number and dimensions and spacings of the system for a given yield. The isoplanatic approximation is not necessary. It is shown that in general the isoplanatic assumption is not valid, although deviations therefrom decrease as the aperture-object distance is increased. It is not necessary to use filtering to remove the contributions at the zeroes of the aperture transform. Noise reduction is performed using Singular Value Decomposition, which is much more selective in picking out the eigenvectors that contribute most to noise. Using simulated ICF implosions, a noise-reduction algorithm will be demonstrated. Reconstructions using optimal choices for imaging system geometry will be shown for simulated data at different neutron yields.

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

# Observation of a hydrodynamically driven, radiative-precursor shock

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Many astrophysical systems, such as supernova remnants and jets, produce radiative-precursor shock waves. In a radiative-precursor shock, radiation from the shock ionizes and heats the medium ahead of it. The simulation of such systems requires that one treat both the emission and the absorption of the radiation. This motivates our experimental design, both as a direct demonstration of the phenomenon and as a test case for astrophysical simulation codes. An important goal of this effort is to produce an experiment that can be modeled without implementing laser absorption physics into an astrophysical code. We report here the first measurements of a radiative-precursor shock in such an experiment.

The experimental design is based on a past experiment[1,2] that used the Nova laser facility to simulate young supernova remnants. The target consists of a 60 μm CH plastic plug followed by a 150 μm vacuum gap and 2 mm of $SiO_2$ aerogel foam. For the experiment, the density of the components and the laser-irradiation conditions are chosen so that the driven shock will produce an observable radiative precursor. We observed the radiative-precursor by using absorption spectroscopy. By backlighting the silicate aerogel foam with a thulium backlighter, we were able to observe both the 1s-2p and 1s-3p lines. These observations will allow us to determine the temperature profile in the precursor. Measurements of the length of the radiative precursor under various experimental conditions will be presented.

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Work supported by the U.S. Department of Energy both directly and through the Lawrence Livermore National Laboratory

31st ANNUAL ANOMALOUS ABSORPTION CONFERENCE

# Rayleigh Taylor Growth Exponents at Decelerating Interfaces

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The Rayleigh Taylor (RT) instability is important in a number of research contexts. We are concerned here with the simple evaluation of RT growth for purposes of design and analysis of experiments. In this context, it is often useful to know the growth exponent of an interface, even when the growth is strongly nonlinear. The growth exponent is defined as the number of linear e-foldings by which initial perturbations at the interface would be amplified, if they remained in the regime of linear amplification. Even though the interfaces in actual experiments often develop very nonlinear structures, the growth exponent can still be useful, as a characterization of the degree of nonlinearity. Here we are concerned with the calculation of growth exponents, under simple assumptions, at a decelerating interface. Decelerating interfaces are important in any impulsively driven system, including supernovae, stellar eruptions, and laboratory studies of hydrodynamic turbulence.

We have analytically evaluated the RT growth for several models that reasonably approximate the experimental possibilities. The reference model is constant deceleration to rest, although this is not very feasible to accomplish experimentally. One can accomplish a constant deceleration over some distance, so we have examined this case. One can also accomplish the deceleration of Sedov-Taylor blast waves. We have calculated the resulting RT growth for 1D, 2D, and 3D expansions. One can also produce, and we have analyzed, the gradual deceleration of a massive flyer plate (or its plasma equivalent). We will present these calculations and compare their results.

Work supported by the U.S. Department of Energy

LA-UR-01-2317
Poster-Preferred

# A 3-D Ray-Trace Model for RAGE

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We describe a new ray-trace algorithm, under development for the modeling of laser-matter-interactions in the 3-D Eulerian Adaptive Mesh Refinement code RAGE[1]. Ray "particles" are deflected in refraction by density gradients, area weighted to local positions along their trajectories. Energy is absorbed in the background and target by inverse-bremsstrahlung and dump-all. The particles can be strung together in fronts to smooth the deposition. Particle splitting can be employed with mesh refinement. The ray trajectories and target response are rendered in rich 3-D perspective with EnSight graphics.

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# *Modeling laser material strength experiments*

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We have done many experiments on the Omega and Janus lasers to measure material strength and other properties of Al, Si and Cu at high pressures (100 kb – 1 Mb) and strain rates (1.e5 – 1.e8). These experiments are diagnosed by VISAR (velocity measurement), x-ray diffraction and material recovery. We simulate these experiments with the Steinberg-Guinan constitutive model that includes shear strength, yield and melting temperature as a function of pressure and temperature.

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Experimental studies of Inertial Confinement Fusion (ICF) Double Shell Implosions with nearly 1D behavior in cylindrical and tetrahedral hohlraums

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Experimental observations of ICF implosions using capsules with two concentric shells separated by a low density region (double-shells) are reported. Capsule designs which attempt to mitigate Au M-band radiation asymmetries by suppression of M-band absorption in the inner capsule are seen to closely follow one-dimensional radiatively driven hydrodynamic simulations in both cylindrical (NIF style) and tetrahedral (Omega style) hohlraums. These M-band asymmetries are caused by concentration of the M-band radiation at the laser spot location, in contrast to the much more uniform thermal radiation environment in a hohlraum. The tetrahedral hohlraum has a much better thermal symmetry than the cylindrical hohlraum, but perhaps poorer M-band symmetry due to the clustering of laser spots around the entrance holes needed to provide the best thermal environment. These M-band asymmetries are a leading candidate for the degradation of performance historically seen in double shell implosions in ICF hohlraums. Previously, one of our capsule designs which mitigated this asymmetry in a tetrahedral hohlraum achieved 50% of the clean 1D calculated neutron yield (YOC) at a convergence ratio (CR) of 25.5, comparable to that of a non-cryogenic double-shell design for an ignition capsule at the National Ignition Facility. This report will discuss recent experimental results using double shell targets mounted in cylindrical hohlraums, which had historically had YOC values of at best a few % at high CR, and compare those results to our previously reported results in the tetrahedral hohlraum. These recent experiments have produced substantially equivalent results to those using tetrahedral hohlraums in our earlier experiments (Varnum, et. al, PRL 84,5153(2000)). Observed neutron yields of 50% to 100% of clean 1D calculations were seen in a number of shots with convergence ratios up to 38. Measurements of fuel $\rho R$, albeit with large error bars due to statistics, essentially match calculated $\rho R$ values, re-enforcing the nearly unity YOC values observed. Imploded core images and neutron yield (measured versus calculated) will be shown for all experiments. Plans for direct-drive double-shell experiments, which completely eliminate the deleterious effects of Au M-band drive asymmetry, will also be discussed.

# 31st Annual
# Anomalous Absorption Conference

## Friday, June 8, 2001

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| **9:00 a.m. – 12:20 p.m.** | **Oral Session 5** |
| **12:20 p.m.** | **Lunch** |

# Precision One-Dimensional *LILAC* Simulations of CH-Shell Implosions on the OMEGA Laser

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In direct-drive inertial confinement fusion, one-dimensional hydrodynamic codes are used extensively to analyze current experiments and to design targets for the National Ignition Facility. Hydrodynamic codes contain one major free parameter, the flux limiter, which models the effect of nonlocal transport in the diffusion representation of the thermal electron conduction. The flux limiter affects the absorption fraction and the mass ablation rate and, therefore, the final performance of the target. In the past, the value of the flux limiter was determined by comparing simulation results with the measured laser absorption and glass-shell trajectory. Both measurements were not sensitive enough to pin down the value of the flux limiter to better than 20%; also trajectories of plastic shells are more difficult to image than glass-shell trajectories. Recently, experimental conditions on the OMEGA laser have been improved considerably, including stable pulse shapes, incident energy, and illumination uniformity, so that the neutron burn history recorded with the neutron temporal diagnostic (NTD) gives measurements that are more sensitive to the flux limiter than the shell trajectories. The timing of the onset of neutron production at the time of shock convergence at target center (shock neutrons) and the timing of peak production are both sensitive to the value of the flux limiter, but the timing of peak production can be shifted to earlier times because of the mixing of the shell into the fuel during stagnation. Results from simulations with varying flux-limiter values are compared with experimental NTD measurements of neutron rates from plastic shells irradiated with two laser pulse shapes: a 400-ps square pulse, which clearly separates the shock yield from the main yield, and the generic 1-ns square pulse used in mix experiments on the OMEGA laser facility. Comparison with the measured absorption fraction and with results of Ar-doped DD-filled targets will also be presented.

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prefer oral session

# Core-Mix Measurements of Direct-Drive Implosions on OMEGA

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High-density, direct-drive implosions have been performed on the 60-beam OMEGA laser system with 1-THz, 2-D smoothing by spectral dispersion (SSD) and polarization smoothing (PS). These implosions have been diagnosed with time-resolved, Ar *K*-shell spectroscopy, fuel $\rho R$ measurements, neutron burn history, and gated x-ray core images. Plastic shells with an Ar-doped deuterium fill gas were imploded with a 24-kJ, 1-ns square laser pulse with full laser beam smoothing and on-target beam-to-beam power imbalance less than 5% rms. The emissivity-averaged core electron temperature ($T_e$) and density ($n_e$) were inferred from the measured time-dependent Ar *K*-shell spectral line shapes. The relative timing of the peak $n_e$ and $T_e$ is compared with the peak neutron production, and spectroscopically determined densities are compared with nuclear measurements of fuel $\rho R$ and gated x-ray images of the core to determine the amount of shell mass mixed into the core. Dopant levels of Ar were minimized to reduce the impact of the enhanced radiative losses on target performance. As the imploding shell decelerates, $T_e$ rises from ~1 keV to ~2.0 keV and $n_e$ increases from ~$0.2 \times 10^{24}$ cm$^{-3}$ to ~$3 \times 10^{24}$ cm$^{-3}$ for targets with convergence ratios of ~15. The peak $T_e$ and peak neutron burn both occur ~100 ps before the peak x-ray emission. Measurements of capsules with higher convergence ratios will also be presented.

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Prefer oral session

# One-Dimensional Simulation of the Effects of Unstable Mix on Neutron and Charged-Particle Yield from Laser-Driven Implosion Experiments

R. Epstein, J. A. Delettrez, V. Yu. Glebov, V. N. Goncharov, P. W. McKenty, P. B. Radha, S. Skupsky, V. A. Smalyuk, and C. Stoeckl

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The effects of Rayleigh–Taylor flow in recent laser-driven implosion experiments are simulated in one dimension by the hydrodynamics code *LILAC*. Mix is modeled as a diffusive transport process affecting material constituents, thermal energy, and turbulent mix-motion energy within a growing mix region whose boundaries are derived from a saturable, linear, multimode model of the Rayleigh–Taylor instability. The linear growth rates and the feedthrough coupling between perturbations of different unstable interfaces are obtained analytically in terms of the one-dimensional fluid profiles. Mode evolution proceeds according to equations applicable to all phases of acceleration, and the effects of geometrically converging, compressible flow are taken into account. The initial perturbations are due to beam-energy imbalance, hydrodynamic imprint of short-scale laser nonuniformity, and target surface roughness. The mix modeling within *LILAC* allows the effects of fuel–pusher mix on burn history, neutron source temperature, and secondary particle yields to be characterized and compared with data from implosion experiments. The limitations of one-dimensional mix as an approximation to the multidimensional distortion of the fuel–pusher interface will be considered.

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prefer oral session

**Green light targets for NIF**

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The ways in which we might use NIF could change dramatically if both target physics and the final optics allowed us to use the large amount of 2ω light that NIF appears to be capable of producing. Consequently, we have initiated a theoretical and experimental effort to explore possible 2ω operations. This work includes quantitative assessments of potential NIF targets assuming LPI can be controlled as well as work to explore the possibilities for having acceptable levels of LPI in a 2ω NIF target. Here we present an analysis of 2ω targets assuming LPI can be controlled. This work includes assessments of 2ω ignition targets as well as 2ω targets for efficiently generating multi-keV x-rays. This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

# Indirectly-driven noncryogenic double-shell ignition target designs for the National Ignition Facility

Peter Amendt, J. Colvin, M.J. Edwards, O.L. Landen, K.O. Mikaelian, J.D. Ramshaw, D. Rowley, L.J. Suter, R.E. Tipton and W.S. Varnum*

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The National Ignition Facility (NIF), in its current 3ω 1.8 MJ baseline design, is planned to demonstrate thermonuclear ignition within the next ten years. The proposed ignition target is a single-shell cryogenic low-Z capsule designed to have relatively low Rayleigh-Taylor growth of surface perturbations and thereby avoid the nonlinear mix regime. However, fabricating, transporting and fielding a cryogenic target is a technically challenging task. For these reasons non-cryogenic double-shell targets are attracting increasing attention as an additional ignition design that avoids the challenge of cyrogenic target preparation. Highly evolved nonlinear mix is characteristic of double-shells because of the absence of ablative stabilization on the outer surface of the high-Z inner shell and the presence of high Atwood numbers on the inner surface. The challenge with double-shell target designs is controlling the degree of nonlinear mix to tolerable levels for achieving ignition.

We present current indirectly-driven double-shell capsule designs which aim to demonstrate ignition on the NIF. Two-dimensional integrated hohlraum simulations are required to verify robust symmetry control for double-shell capsules in advanced hohlraums,[1] i.e., hohlraums with high laser-coupling efficiency. For example, localized L-shell emission from the high-Z hohlraum wall leads to non-uniform absorption by the high-Z inner shell of the double-shell target. Such a new and potentially important source of flux asymmetry will require auxiliary control. A suite of double-shell target designs spanning hohlraum temperatures from 200eV to 300eV is presented. The relative stability merits of each design is explored through use of various Youngs[2]-type atomic mix models, e.g., the Ramshaw model[3] for nonlinear mixing.

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[3] J.D. Ramshaw, Phys. Rev. E **58**(5), 5834 (1998).

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

# Hydrodynamic Stability of Moderate- to High-Gain Direct-Drive Target Designs for the NIF

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Hydrodynamic stability of two classes of direct-drive inertial confinement fusion capsule designs is analyzed by using postprocessor[1] to the 1-D hydrodynamic code *LILAC*. The first class consists of moderate-gain, "all-DT" targets driven on different isentrope $\alpha$. The high-gain targets of the second class (G > 120 in 1-D) are made of a layer of cryogenic DT surrounded by "wetted" CH foam. An increased laser absorption of targets in the second class allows an increase in shell thickness, reducing effects of hydrodynamic instabilities on capsule performance. It is shown that an additional Rayleigh–Taylor perturbation growth at the classical interface (with At ~ 0.1) between wetted foam and DT ice does not compromise shell integrity.

1. V. N. Goncharov *et al.,* Phys. Plasmas **7**, 5118 (2000).

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