18th Annual
Anomalous Absorption Conference

l'Estérel, Québec
June 27 – July 1, 1988

National Research Council of Canada
Conseil National de Recherches du Canada

Canada

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Anomalous Absorption Conference

Hôtel l'Estérel
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Hosted by the National Research Council of Canada

Conference Chairman: Hector A Baldis
Conference Coordinator: David M Villeneuve
Conference Secretary: Carolyn Kingston

National Research Council Canada
Conseil national de recherches Canada

Division of Physics
Division de physique

18th Annual Anomalous Absorption Conference
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——————— **Monday Morning, 8:30 AM, June 27** ——————— *(P D Goldstone, Chair)*

Invited Talk (30 minutes)

A1 Short pulse laser produced plasmas – the overall picture;
Barry Luther-Davies.

A Transport (Oral Session)

A2 Rayleigh-Taylor instability, flutes, and jets in expanding laser-produced plasmas;
B H Ripin, C K Manka, T A Peyser, E A McLean, A N Mostovych, C Pawley, J Grun and J A Stamper.

A3 Investigation of the Rayleigh-Taylor instability in colliding PHAROS III laser targets;
J P Dahlburg, J H Gardner and M H Emery.

A4 Stopping and thermalization of interpenetrating plasma streams;
R L Berger, J R Albritton and C J Randall.

A5 Measurements of the heat flux, inverse Bremsstrahlung absorption and equilibration in an under-dense laser heated plasma;
A Dyson, A E Dangor and A K L Dymoke-Bradshaw.

A6 Calculations of collisional energy deposition in short scale length plasmas;
D D Meyerhofer, R S Craxton and J Delettrez.

A7 Adiabatic invariants and generalized ponderomotive action on single particles;
P Mulser, W Schneider and M O Scully.

A8 Intrinsic conversion efficiency in the conversion layer of laser heated disks;
L J Suter.

A9 Non-local thermal smoothing effects in laser-produced plasmas;
E M Epperlein.

A10 Dynamics of Au plasmas produced by temporally shaped laser pulses;
B H Failor, E F Gabl, Gar E Busch, R J Schroeder, C J Armentrout and Z Koenig.

A11 Hydrodynamic response of ISI-smoothed laser ablatively accelerated targets;
M H Emery, R H Lehmberg, S P Obenschain, A N Mostovych and J Grun.

——————— **Monday Evening, 7:30 PM, June 27** ——————— *(R R Johnson, Chair)*

Review Talk (45 minutes)

R1 Review and perspectives of parametric instabilities in laser plasmas;
C S Liu.

B Mixed Poster Session

B1 Efficiency enhancement of the conjugate signal for a colinear four wave mixing process;
G G Luther, S H Batha and C J McKinstrie.

B2 Theoretical analysis of recent KMS gold disk experiments;
W B Fechner.

B3 Critical and 1/4 critical density trajectories in high-Z planar targets;
R J Schroeder, E F Gabl, B H Failor, W B Fechner and K L Marsh.

B4 Mix of laser accelerated packages measured by point projection spectroscopy and imaging microscopy;
J D Kilkenny, S G Glendinning, D Munro, D Bach, R Wallace, T J Goldsack, P Fieldhouse and K Oades.

C9 Observations of Raman up-scatter in a long scale length plasma;
S H Batha, D D Meyerhofer, W Seka, A Simon, L M Goldman, C B Darrow, R P Drake and D S Montgomery.

C10 The effect of induced spatial incoherence on stimulated Raman scattering;
P N Guzdar, W Tan, Y C Lee, C S Liu and R Lehmberg.

C11 Energy and nonlinearity considerations for the enhanced plasma wave model of Raman scattering;
A Simon and R W Short.

—————— **Tuesday Evening, 7:30 PM, June 28** —————— *(F Amiranoff, Chair)*

Review Talk (45 minutes)

R2 The physics of beat excited plasma waves;
C Joshi.

D Mixed Poster Session

D1 Coupled non-LTE electron and ion population distributions;
K G Whitney, P E Pulsifer, P C Kepple, J T Pender and N R Pereira.

D2 Radiation cooling in plasmas containing layers of high Z and low Z materials;
J C Moreno, S Goldsmith, H R Griem and J Knauer., P. Jaanimagi, D Bradley

D3 Density gradient effects in the competition between stimulated Raman scattering and stimulated Brillouin scattering;
L V Powers, R L Berger and J P Sheerin.

D4 X-ray imaging of radiatively driven implosions;
J D Kilkenny, F N Ze, R E Turner, S P Hatchett and L J Suter.

D5 Thomson scattering measurements of temperature and density in a hot dense laser plasma;
J E Bernard, H A Baldis and D M Villeneuve.

D6 Time-resolved gating with microchannel plates;
R E Turner, P Bell, R Hanks, J D Kilkenny, G Power and J Wiedwald.

D7 Time-resolved x-ray albedo measurements;
F Ze, L Suter, E M Campbell and J D Kilkenny.

D8 Modeling time dependence and conversion efficiency in gold–beryllium disks;
S Langer, D Kania, R Kauffman, R Kornblum and F Ze.

D9 Kinetic simulations of high intensity picosecond laser-target interaction;
J P Matte, J C Kieffer, P Audebert, M Chaker and H Pépin.

D10 Resonant self-focusing in the beat-wave accelerator;
D A Russel and C J McKinstrie.

D11 Laser-plasma instabilities in large ICF-related plasmas: survey of thresholds and simple target modeling;
R D Jones, B B Bezzerides and W C Mead.

D12 Physics and design issues and applications for a proposed ICF intermediate driver;
W C Mead, S V Coggeshall, P D Goldstone, R D Jones, A A Hauer and G R Magelssen.

D13 Multilayer targets and direct drive laser fusion;
W Seka, F Amiranoff and C Garban-Labaune.

D14 Energy transfer in the NLS model of Langmuir turbulence for an inhomogeneous plasma;
O Larroche and D Pesme.

D15 Frequency up-conversion of electromagnetic radiation using an overdense plasma;
S C Wilks, J M Dawson and W B Mori.

D16 Enhanced Raman scattering in a flowing plasma;
R Dragila and S Vukovic.

D17 Study of shock coalescence in laser irradiated targets;
S E Coe, O Willi, T Afshar-Rad and S J Rose.

——————— **Wednesday Morning, 8:30 AM, June 29** ——————— *(G D Enright, Chair)*

Invited Talk (30 minutes)

E1 Effects of ISI on Raman emission;
S.P. Obenschain, C K Manka, T A Peyser, K J Kearney, A N Mostovych, C J Pawley, J A Stamper and A J Schmitt.

E ICF and Related Topics (Oral Session)

E2 Compression measurements for implosions at Nova;
M D Cable, S M Lane and S G Glendinning.

E3 Cryogenic-laser-fusion-target implosion studies performed with the Omega UV laser system;
F J Marshall, S A Letzring, C P Verdon, R L Kremens, S Skupsky, R L Keck, J P Knauer, D K Bradley, T Kessler, J A Delettrez, H Kim, J M Soures and R L McCrory.

E4 Non-LTE simulation of time-dependent features of x-ray spectra from high-Z targets;
R Epstein, J Delettrez, D K Bradley and P A Jaanimagi.

E5 Recent experimental measurements of laser burnthrough on plastic coated microballoons;
D K Bradley, J Delettrez, R Epstein, C Hestdalen and P A Jaanimagi.

E6 Theoretical analysis of burnthrough experiments in targets with barrier layers;
J Delettrez, D K Bradley, R Epstein and P A Jaanimagi.

E7 Plasma evolution in laser-irradiated hollow microcylinders;
J E Balmer, R Weber, P F Cunningham and P Lädrach.

E8 Magnetic pulse generation by a combined scheme of laser-irradiation and laser-compression;
W Choe and J Seely.

E9 Effect of a random phase plate on the laser-driven ablation process;
P A Holstein, B Meyer, D Galmiche and M Rostaing.

E10 The effects of hydrodynamic flow on thermal filamentation;
A J Schmitt.

——————— **Wednesday Evening, 6:00 PM, June 29** ——————— *(H A Baldis, Chair)*

F Banquet and Business Meeting

Review Talk (45 minutes)

R3 18 Years of Anomalous Absorption;
T W Johnston.

——————— **Thursday Morning, 8:30 AM, June 30** ——————— *(J M Soures, Chair)*

Invited Talk (30 minutes)

G1 Observations of high density plasmas produced with picosecond high power KrF irradiation;
O Willi, G Kiehn, J Edwards, V Barrow, R A Smith, J Wark and E Turcu.

G Beat Waves, X-ray Lasers and Short Pulses (Oral Session)

G2 Electron non-linearities in Langmuir waves with application to beat-wave experiments;
A R Bell and P Gibbon.

G3 Static plasma density modulation for a laser-plasma-accelerator;
M Laberge and J Meyer.

G4 The modulational instability and its consequences for the beat wave accelerator;
P Mora, D Pesme, A Héron, G Laval and N Silvestre.

G5 Cascade focussing in the beat-wave accelerator;
P Gibbon and A R Bell.

G6 Airy acceleration: How to get 2 MeV electrons from the $c/\sqrt{3}$ phase velocity waves at $n_c/4$;
T W Johnston and S Aithal.

G7 Two-dimensional hydrodynamics and refraction in x-ray laser experiments;
R S Craxton.

G8 Heated electron distributions resulting from optical field induced ionization;
N H Burnett and P B Corkum.

G9 Interaction of psec pulses with solid targets at high intensities;
P Audebert, M Chaker, J C Kieffer, H Pépin, J P Matte, P Maine, D Strickland, P Bado and G Mourou.

G10 Experimental study of 20 ps laser produced plasmas;
H A Baldis, R Barnsley, J Dunn, M H Key, P Norreys, S Rose and G J Tallents.

G11 Interaction of intense femtosecond laser pulses with matter;
P Mulser, S Pfalzner and F Cornolti.

Thursday Evening, 7:30 PM, June 30 *(J Meyer, Chair)*

Review Talk (45 minutes)

R4 Anomalous negative absorption: Plasma and atomic physics issues in laboratory x-ray lasers;
M D Rosen.

H Mixed Poster Session

H1 Survey of recent KMS gold disk experiments;
C J Armentrout, E F Gabl, B H Failor, Gar E Busch, R J Schroeder and Z Koenig.

H2 Pulse length dependence of x-ray conversion efficiency;
D R Kania, F Ze, H Kornblum and J D Kilkenny.

H3 X-ray emission from gold:beryllium mixtures;
D R Kania, S Langer, H Kornblum, R L Kauffman, S G Glendinning and R E Turner.

H4 Measurements of plasma conditions in exploding foil x-ray laser amplifiers;
D L Matthews, B Young, M D Rosen, C Keane, B MacGowan, R London, S Maxon and G Charatis.

H5 Space-, frequency-, wavenumber- and time-resolved images of SRS and SBS in a preformed plasma;
D M Villeneuve, H A Baldis and J E Bernard.

H6 X-ray conversion of 0.35 μm light from uranium disk targets;
R L Kauffman, D R Kania and H Kornblum.

H7 Modelling of gold dot irradiations;
B F Lasinski, D R Kania, S G Glendinning, C B Darrow, H N Kornblum, S H Langer, P E Young, F Ze and R E Turner.

H8 X-ray spectroscopy of laser produced plasmas using a transmission grating;
V Bareau, M Chaker, J C Kieffer, H Pépin, J E Bernard, D M Villeneuve and H A Baldis.

H9 Self-focusing in long scalelength plasmas;
R Rankin, C E Capjack and C R James.

H10 Simulations and analysis of a recent spherical x-ray conversion efficiency experiment;
S V Coggeshall, P D Goldstone, W C Mead, D K Bradley, P A Jaanimagi, J Knauer, F J Marshall, G Pien and M C Richardson.

H11 Observation of symmetry-, density-, and Z-dependence of x-ray conversion;
P D Goldstone, J A Cobble, W C Mead, S V Coggeshall, D K Bradley, P A Jaanimagi, J Knauer, F J Marshall, G Pien, M C Richardson, J F Seely and U Feldman.

H12 Stimulated Raman scattering (SRS) and ion-sound wave dynamics in homogeneous plasma;
G Bonnaud and D Pesme.

H13 Transient stage in the nonlinear evolution of the parametric instabilities;
M Casanova, G Laval, D Pesme and N Silvestre.

H14 Four-wave mixing and phase conjugation in a plasma with density fluctuations;
J F Federici and E J Valeo.

H15 Wavebreaking of relativistic plasma waves in a thermal plasma;
W B Mori and T Katsouleas.

H16 Acceleration of electrons in an underdense plasma containing fluctuations of magnetic field on a background large scale DC magnetic field;
R Dragila.

H17 **Post Deadline Papers;**

——— Friday Morning, 8:30 AM, July 1 ——— *(B F Lasinski, Chair)*

Invited Talk (30 minutes)

I1 Experimental evidence for nucleation and collapse of Langmuir cavitons in the interaction of high frequency radiation with plasmas;
D F DuBois.

I Parametric Instabilities, Filamentation and Langmuir Turbulence (Oral Session)

I2 Chaos and soliton formation during nonlinear resonance absorption in inhomogeneous laser produced plasmas;
W Shyu, H H Chen, C S Liu, Y C Lee and P N Guzdar.

I3 Simulations of ultra-strong Langmuir turbulence in open systems;
J P Sheerin.

I4 Heating of electrons by localized Langmuir waves (Beyond the ponderomotive potential approximation);
W Rozmus and P Goldstein.

I5 Excitation of strong Langmuir turbulence in HF heating of the ionosphere;
D F DuBois, H A Rose and D A Russel.

I6 Almost degenerate four-wave mixing;
E A Williams, J DeGroot and S Cameron.

I7 Experimental study of filamentation in laser-produced plasmas;
P E Young, R P Drake, E M Campbell, K G Estabrook and H A Baldis.

I8 The effect of self-focusing on hot spots in multiple-beam illumination geometries;
R W Short.

I9 Measurements of ion acoustic parametric decay instability;
K Mizuno, P Young, J S DeGroot, R P Drake and W Seka.

I10 Effects of ISI on stimulated Brillouin scattering;
A N Mostovych, C J Pawley, S P Obenschain, J A Stamper and M H Emery.

I11 Simultaneous spatially and spectrally resolved measurement of $3\omega_0/2$ emission from a laser-produced plasma;
P E Young, W L Kruer, B F Lasinski, E A Williams, K G Estabrook, A B Langdon, E M Campbell and H A Baldis.

Invited Talk (30 min) A1

18th Anomalous Absorption Conference, l'Estérel, Quebec, June 26-July 1 1988

Short Pulse Laser Produced Plasmas – The Overall Picture

Barry Luther-Davies

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Research School of Physical Sciences
The Australian NAtional University
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Australia

Abstract

For around ten years the research on laser-produced plasmas at the Australian National University has concentrated on understanding the physics of plasmas produced by relatively short (20-100psec) 1μm laser pulses at very high intensities: $I \approx 10^{14}$ to $I > 10^{18}$W/cm^2. Ion density fluctuations in these plasmas can be invoked to explain a very large number of experimental observations. They most probably play a dominant role in absorption by enhancing the inverse Bremsstrahlung process; they can produce speckle patterns in the spatial distribution of harmonic light emitted from the plasma which because the harmonic spectra are determined by self-phase modulation can lead to apparent temporal pulsations of that emission; they can result in the generation of axial magnetic fields through the action of a turbulent dynamo; they can result in instabilities of the critical surface in magnetised plasmas; and via SBS generate strong self-phase modulation of emission at harmonics of the laser frequency leading to spectral broadening and modulation. Taking the "density fluctuation" theme, this talk will review our work in this area.

A2

Rayleigh-Taylor Instability, Flutes, and Jets in Expanding Laser-Produced Plasmas

Rec'd. 6

B.H. Ripin, C.K. Manka, T.A. Peyser,[a] E.A. McLean, A.N. Mostovych, C. Pawley, J. Grun, and J.A. Stamper

U.S. Naval Research Laboratory
Washington, D.C. 20375

An interesting form of the Rayleigh-Taylor instability occurs when a plasma (heavy fluid) expands into a magnetic field (light fluid). We observe the linear and nonlinear development of such an instability in laser-created plasma in which the electrons have small Larmor radii yet the ions are effectively unmagnetized.[1] Dramatic flutes grow rapidly beyond a threshold radius and exhibit unusual features, such as: initial density clumping, free-streaming flute tips, bifurcation and spiral-like structures.[2] These experiments are in a similar regime to some magnetospheric barium release experiments, such as AMPTE.[3] In different, but closely related experiments, laser-produced plasma jets are formed which cut many Larmor radii across the magnetic field with little loss of velocity.[4] The E x B force on the plasma is responsible for the cross-field motion; E is the polarization electric field inside the plasma.[5] These plasma jets also exhibit unanticipated instability structure.[4,5]

[a]SAIC, McLean, VA

[1]J.D. Huba, J. Lyons, and A.B. Hassam, Phys Rev Letters 59, 2971 (1987).
[2]B.H. Ripin, et al., Phys Rev Letters, 59, 2299 (1987).
[3]P.A. Bernhardt, et al., J. Geophys. Res. 92, 5777 (1987).
[4]B.H. Ripin, et al., NRL Memo Report 6154 (March 1988); also to be published in Laser Interactions and Related Plasma Phenomena, Vol. 8, Eds. H. Hora and G. Miley (Plenum Press, NY, 1988).
[5]A.N. Mostovych, B.H. Ripin, and J.A. Stamper, to be published in Rev. Sci. Insts. (1988).

This work was supported by the Defense Nuclear Agency.

Investigation of the Rayleigh-Taylor Instability in Colliding PHAROS III Laser Targets

J. P. Dahlburg, J. H. Gardner,
and M. H. Emery

The Laboratory for Computational Physics & Fluid Dynamics
Naval Research Laboratory, Washington, DC 20375

Abstract. We investigate by means of numerical simulation the laser-driven collision of a rectilinear target with a solid boundary in the presence of the ablative Rayleigh-Taylor instability[1,2] on the outer, laser-irradiated, target surface. Parameters for most of the simulations reported are chosen to match closely those of recent PHAROS III $0.537\mu m$ experiments, with approximately $5ns$ FWHM Gaussian laser intensity profiles which peak at 1×10^{13}, and $12\mu m$ thick plastic targets. Results from these simulations indicate that the target's inner surface becomes unstable to the Rayleigh-Taylor instability during compression of the low-density buffer material separating the targets. Localized peaks in density on the inner side of the target are observed to develop subsequent to shock passage and reflection from the image plane separating the targets. These peaks generally arise in the neighborhood of local pressure jumps. In all simulations performed, the instability which grows on the outer surface is well-separated at early times from those which can be induced on the inner surface by a quiescent buffer of lower-density target material. This target profile continues until the relatively uniform linear acceleration of the targets is decreased in response to the inner region pressure build-up. As the acceleration of the targets reverses, the inside becomes unstable to the Rayleigh-Taylor instability and the outside is stabilized. Simultaneously with the compression, the inner density peaks are absorbed by the outer, and some "mixing" can be said to be observed. This "mixing" does not appear to be a direct function of any nonlinear advective hydrodynamic process, but instead appears to arise as a consequence of the proximity and coalescence of the outer surface Rayleigh-Taylor instability with that which is induced in the inner region.

[1] Emery, M. H., Orens, J. H., Gardner, J. H. & Boris, J. P. *Phys.Rev.Lett.* **48**, 253, (1982).

[2] Emery, M. H., Dahlburg, J. P. & Gardner, J.H. *to appear, Phys.Fluids*, (April, 1988).

Supported by the U. S. Dept. of Energy

STOPPING AND THERMALIZATION OF INTERPENETRATING PLASMA STREAMS

R.L. Berger, KMS*; J.R. Albritton and C.J. Randall, LLNL**

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Ann Arbor, MI 48106

**Lawrence Livermore National Laboratory

Livermore, CA 94550

Double foils have been illuminated with high power laser beams to create large regions of uniform plasma between the foils. Such uniform plasmas are favorable media for x-ray laser or parametric instability studies. The plasma between the foils consists of two oppositely moving streams that, if they can freely interpenetrate, will produce very uniform plasma with low ion temperature. Estimates of the stopping distance for the counterstreaming ions due to ion-ion Coulomb collisions or to two-stream instabilities show these effects are weak in cases of interest. We have developed a two ion fluid model to follow the space and time evolution of the ion density, velocity, and temperature of each stream and the density and temperature of the charge neutralizing isothermal electrons. We find the small kinetic energy loss due to ion-ion collisions results in moderate but significant ion heating over an extended region of plasma between the foils. In comparison, a standard single ion fluid model results in a highly localized region of high ion temperature at the midpoint between the foils.

A5

MEASUREMENTS OF THE HEAT FLUX, INVERSE BREMSSTRAHLUNG ABSORPTION AND EQUILIBRATION IN AN UNDER–DENSE LASER HEATED PLASMA

A Dyson, A E Dangor, A K L Dymoke–Bradshaw

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Abstract – A fully ionised hydrogen plasma of initial density $\approx 5\ 10^{18}cm^{-3}$ and temperature ≈12eV is heated using a 1.053μm laser beam focussed to a spot of 200μm diameter with an irradiance of $5\ 10^{13}Wcm^{-2}$. The resulting evolution of the plasma is monitored by Thomson scattering of a second laser beam at 5265A. Comparison with a one–dimensional two fluid hydrodynamic simulation shows that the inverse bremsstrahlung absorption coefficient should be modified to include the strong field correction and that the maximum heat flux is about 0.1 of the free streaming limit. The ratio of the electron mean free path to the temperature scale length is about 0.1 and $T_e/T_i \approx 5$. The level of ion acoustic turbulence is observed to be small, close to thermal. The ion–electron equilibration rate is found to agree with the usual classical value.

A6

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CALCULATIONS OF COLLISIONAL ENERGY DEPOSITION IN SHORT SCALE LENGTH PLASMAS

D.D. Meyerhofer, R.S. Craxton, and J. Delettrez

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Abstract

In the interaction of short pulse lasers with matter, the laser wavelength may be longer than the density scale length. If this is the case, there can be significant amounts of collisional energy deposited at densities higher than critical due to the skin effect. The collision rate can increase more rapidly in space than the evanescent wave decays, enhancing the power deposition. This effect is important in both the interaction of picosecond lasers with matter, and in the use of short pulse lasers to produce recombination x-ray lasers. Calculations using simplified profiles and results of including this effect in the 1-D hydrodynamics code LILAC will be presented.

"This work was supported by the U.S. Department of Energy Office Of Inertial Fusion under agreements No. DE-FC08-85DP40200 and by the Sponsors of the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics."

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Adiabatic Invariants and Generalized Ponderomotive Action on Single Particles

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and

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We have deduced an adiabatic invariant for open periodic orbits to generalize the commonly used expressions for the ponderomotive potential and force in the case when a scalar potential exists. By applying our invariant to the electrons moving into a longitudinal electric wave we showed the appearance of a hysteresis in phase space which clearly illustrates that the classical ponderomotive potential is of asymptotic validity (weak fields) only. With the construction of an effective Hamiltonian we are able to apply the same invariant to electromagnetic fields and to calculate the wave pressure $\vec{f}_p$ on charged particles for arbitrarily high field strengths. Finally we extended our procedure to particles with internal degrees of freedom and obtained their laws of motion in the most immediate way and with minimum formal effort. The results obtained and the methods applied are relevant for particle acceleration by waves in laser plasmas and current drive by wave injection in toroidal plasma machines.

Intrinsic Conversion Efficiency in the Conversion Layer of Laser Heated Disks

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A simple model of a laser heated disk is to view it as a conversion layer, which has some intrinsic conversion efficiency that is greater than the observed conversion efficiency, standing off from a reflecting layer which has an albedo <1. In this paper we will describe Lasnex' scaling of the intrinsic conversion efficiency; show how it varies as a function of laser intensity, how it behaves in time, how it appears to be related to the plasma profile in the blowoff, and how, at ICF laser intensities, it may be significantly increased by modifying the plasma profiles.

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

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NON-LOCAL THERMAL SMOOTHING EFFECTS IN LASER-PRODUCED PLASMAS

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Abstract

A 2-D Fokker-Planck code SPARK has been written to study non-local electron transport effects in the process of thermal smoothing. The code treats the ions as a cold fluid background which is moved under the influence of the pressure calculated from the electron distribution function. The electric potential required to preserve quasi-neutrality is evaluated via an "implicit moment"(1) method which keeps the maximum fractional charge separation below 10^{-3}. Simulations have been done for fully ionized planar targets irradiated by UV laser light of peak intensity 5 x 10^{14} W/cm^2 (600 ps FWHM) with a harmonic spatial modulation of wavelength λ in direction perpendicular to the beam propagation. When comparing the results with simulations from a standard 2-D hydro code with flux limited Spitzer conductivity we find a significant reduction in the smoothing of the ablation surface for $\lambda \simeq 50$ - 150 µm. For $\lambda > 150$ µm the non-local transport effects, responsible for the reduced smoothing, becomes less important.

1. R.J. Mason, J. Comput. Phys. 41, 233 (1981).

"This work was supported by the U.S. Department of Energy Office Of Inertial Fusion under agreements No. DE-FC08-85DP40200 and by the Sponsors of the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics."

DYNAMICS OF AU PLASMAS PRODUCED BY TEMPORALLY SHAPED LASER PULSES

B. H. Failor, E. F. Gabl, Gar. Busch, R.J. Schroeder,

C. J. Armentrout, Z. Koenig

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The interaction of a shaped laser pulse with a high Z target is of interest to indirect drive fusion, because a slowly rising pulse will more efficiently drive a spherical implosion than an abruptly rising one. The CHROMA laser, running in green (2ω), was used to irradiate Au disks with a variety of pulse shapes which included square, slowly rising, and a series of 3 discrete pulses (picket fence) choosen to approximate the slowly rising pulse. For example, the evolution of the electron density profile was determined by a combination of measurements (holographic interferograms, harmonic light streak images, and x-ray streak images) and the sub-keV x-ray emission was monitored by an array of soft x-ray diodes. The plasma density profile produced by a picket fence pulse differed significantly from that produced by a continuous pulse.

Hydrodynamic Response of ISI-Smoothed Laser Ablatively Accelerated Targets

M. H. Emery, R. H. Lehmberg, S. P. Obenschain, A. N. Mostovych and J. Grun
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The induced spatial incoherence method (ISI)[1] method produces a spatial irradiance profile that is smooth on hydrodynamic time scales but undergoes large random fluctuations on picosecond time scales. We have incorporated a model for ISI into our FAST2D LMI Code, which accounts for the number of echelons, the size of the laser spot, the coherence time of the laser and the time delay induced by each echelon. The model produces a spatially and temporally randomly varying beam profile which is in good agreement with theory and experiment.

We present the results from a series of numerical simulations of the target response to an ISI-smoothed laser beam. During the early startup phase of the laser pulse, the large amplitude variations in the ISI irradiance profile can produce shock structures whose imprint on the target can persist for some time. The evolution of this target will be compared and contrasted with targets accelerated by laser beams with zero bandwidth (random phase plate approximation) and with imposed large amplitude irradiance asymmetries. In addition we will discuss the underdense plasma profiles stemming from an ISI-smoothed laser beam. These profiles exhibit some turbulent structure which may provide an explanation for the lack of SBS backscattered spectra with ISI illumination.[2]

[1] R. H. Lehmberg and S. P. Obenschain, Opt. Comm. **46**, 27(1983).

[2] A. N. Mostovych et al., Phys. Rev. Lett. **59**, 1193(1987).

Work supported by the U. S. DoE and ONR.

Review Talk (45 min)

R1

Review and Perspectives of Parametric Instabilities in Laser Plasmas

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EFFICIENCY ENHANCEMENT OF THE CONJUGATE SIGNAL FOR A COLINEAR FOUR WAVE MIXING PROCESS

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Abstract

The canonical nonlinear four wave equations are used to describe the non-degenerate colinear interaction of four electromagnetic waves in a plasma. A general closed form analytic solution is obtained which is used to explore the effect of detuning the incident probe beam away from the pump-probe beam resonance. It is shown that the detuning can enhance the phase conjugate output intensity. The formalism also applies to more conventional four wave interactions in nonlinear optics.

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THEORETICAL ANALYSIS OF RECENT KMS GOLD DISK EXPERIMENTS

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Recent KMS experiments on Au disk targets (referred to hereafter as "Hi-Z" experiments) have shed some light on the state of the plasma produced by a low preheat laser pulse with gaps ("picket fence") at a wavelength of $\lambda_L = 0.53$ μm and an intensity of $I_L = 6 \times 10^{14}$ w/cm^2. The state of the plasma (n, T) will be modelled with a 1-dimensional Lagrangian hydrocode with non-LTE equation of state. The same code will be used to model the effect of the early time plasma blowoff (from the first few pickets) on subsequent absorption and x-ray emission. Two-dimensional effects (e.g. hotspots) on the hydrodynamics and on the optical 4ω interference pattern will be analyzed with a two-dimensional Lagrangian hydrocode with ray tracing. Finally, we will use several of the plasma diagnostics on this experiment to identify the location and origin of the x-ray emission.

CRITICAL AND 1/4 CRITICAL DENSITY TRAJECTORIES IN HIGH-Z PLANAR TARGETS

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Planar gold targets of 500 μm diameters were illuminated with 0.53 μm laser light using square and picket fence 2 nanosecond laser pulses. The picket fence pulse is comprised of three pulses in an intensity ratio of 1:2:3. The first two pulses are 120 psec FWHM spaced 850 psec apart. The third pulse is 750 psec square and arrives 340 psec after the second pulse. Measurements of the critical and 1/4 critical density trajectories were taken from streak measurements of 2 ω and 3/2 ω harmonic light emission. Distinct differences are observable in the surface density motion between the square flat-topped laser pulse and a picket fence pulse. Preliminary data from experiments performed with .351 μm laser light are also presented.

Mix of Laser Accelerated Packages Measured by Point Projection Spectroscopy and Imaging Microscopy*

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When an interface between materials of differing density is accelerated, small perturbations can grow. This can occur in laser-driven fusion both during the inward acceleration of the shell and during the deceleration of the shell by a lower density higher pressure fuel at stagnation. For continuous acceleration this is the Rayleigh-Taylor instability, and is for shock acceleration the Richtmeyer-Meshkov instability. Here we report measurements made on the Nova laser of both the turbulent phase of the instabilities and the linear phase of the instabilities. A novel technique, point projection spectroscopy is used for the turbulent phase of the experiments.

The experiments on the lienar phase (Taylor) of the instabilities measure the growth of a seeded wavelength by radiography normal to the surface of accelerated packages. Predictions are that the growth rate is reduced from the classical $A(ka)^{1/2}$ by the ablation process. We have taken trouble to ensure that our measurements are not compromised by spectral impurity of the x-ray backlighter nor contrast limitations in the Wolter x-ray microscope, and find growth rates approximately in agreement with theory.

For the non-linear phase experiments, there have been no experimental data reported on plasmas. Here a novel technique, point projection spectroscopy is used. Packages with unstable material interfaces i.e. large Attwood numbers, are accelerated by eight of the Nova laser beams. A spectrally continuous backlighter is formed by focussing one of the laser beams of Nova onto a 20 μm fiber, forming a short lived point source of x rays. This projects an image of the package in flight onto a recording film with spectral resolution. We identify the position of the two materials of the package and the amount of mix. Control experiments where mix should not occur because of the low Attwood number, are indeed seen to exhibit little mix. On the unstable targets, the measured mix exceeds the system resolution as measured by the control experimens by more than a factor of two. Agreement with a simple heuristic theory is demonstrated.

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

Time-Resolved Measurements of Indirectly-Driven Implosions on Nova*

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Several time-resolving neutron and x-ray diagnostics are currently fielded on implosion experiments on Nova, providing information on neutron and x-ray production time and production rate. These include GaAs and plastic scintillator neutron diagnostics, a high resolution x-ray microscope, and a GaAs photoconductive diode x-ray detector. We have obtained results on all of these diagnostics for indirectly-driven implosions. We will show comparisons of the results of the different measurement techniques, and we will also show comparisons with LASNEX calculations of these quantities.

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

The Role of Laser Beam Filamentation in Mega-Joule Scale Targets*

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A simple model is used to examine ponderomotive and thermal filamentation in an inhomogeneous, collisional plasma. Thermal filamentation is a concern in the low intensity foot of the laser pulse used to drive a high gain capsule, but can be avoided by operating above some critical intensity. Several favorable irradiation schemes are suggested. We also examine a complementary limit in which hot spots in the laser beam self-focus. Finally, the potential benefits of using smoother laser beams are emphasized.

* 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.

ABSTRACT FOR THE 18th ANOMALOUS ABSORPTION CONFERENCE
Esterel, Québec
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ABSOLUTE SRS IN DENSITY RIPPLES*

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Recently[1] the suggestion was made that absolute instabilities due to density ripples are a plausible source of significant broadband SRS in large systems. Earlier work[2] on the problem of ripples on a ramp has been extended with the object of better specifying thresholds for absolute instabilities in marginal cases, such as weak pumps, extremes of ripple wavelength and small ripple amplitude.

1 R.P. Drake, E.A. Williams, P.E. Young, K. Estabrook, W.L. Kruer, H.A. Baldis and T.W. Johnston, Phys. Rev. Lett. 60(11), 1018 (1988).
2 G. Picard and T.W. Johnston, Phys. Fluids 28(3) 859-868 (1985)

* Ce travail est supporté par le Ministère de l'Education du Québec et par CRSNG Canada.

A nonlinear theory of the stimulated Raman scattering in a homogeneous plasma

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Stimulated Raman scattering of an intense laser beam in a homogeneous plasma is analyzed by means of the 1-d Zakharov equations coupled to a self-consistently calculated sourse. The source term is given in terms of the secondary electromagnetic wave amplitude while the original laser wave is assumed to have constant amplitude (the weak absorption limit). The Rayleigh-Ritz variational method is applied to solve those equations; the trial function has the form of a travelling wave packet with variable amplitude, velocity and width. A system of ordinary differential equations which results from the principle of least action is investigated by means of analytical and numerical methods to pursue the localization and breakdown of the wave packet.

* Visitor from Institute for Nuclear Studies, Warsaw, Poland.

Study of Laser-Plasma Interaction with Picosecond Lasers

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A 700 fs laser operating at 248 nm has been used to irradiate solid targets of various elements (Al, Fe, Au), creating a hot highly transient plasma. The laser energy was as high as 25 mJ giving an irradiance in excess of 10^{17} W/cm^2. Due to the high intensities and short time scales the laser-plasma interaction in this regime is very different than typically studied. The short pulse is preceded by an ASE generated pulse of several ns duration and an intensity < 10^{12} W/cm^2. This pre-pulse creates a cold plasma with an expected electron temperature of no more than 5 eV and a scale length on the order of 50 µm.[1] The laser has been focused using an f/3 off-axis parabola, giving a spot diameter on target of about 4 µm.[1,2] Line profile analysis indicates that the peak of the x-ray emitting region is ~ n_c, suggesting that most of the absorption takes place there. The plasma has been studied using a variety of diagnostics including x-ray and optical spectroscopy, pinhole imaging and PIN diodes. Results and interpretation of the laser-plasma interaction will be presented.

1. J. A. Cobble, et. al., submitted to PRL.
2. J. P. Roberts, et. al., LA-UR-88-822, submitted to Optics Lett.

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THE MODULATIONAL INSTABILITY OF NONLINEARLY-COUPLED WAVES

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The colinear propagation of an arbitrary number of finite-amplitude waves is modeled by a system of coupled nonlinear Schroedinger equations; one equation for each complex wave amplitude. In general, the waves are modulationally unstable with a maximal growth rate which is larger than the modulational growth rate of any wave alone. Moreover, waves which are modulationally stable by themselves can be driven unstable by the nonlinear coupling. The general theory is then applied to the relativistic modulational instability of two laser beams in a beat-wave accelerator. For parameters typical of a proposed beat-wave accelerator, this instability can seriously distort the incident laser pulse-shapes on the particle-acceleration time scale, with detrimental consequences for particle acceleration.

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18th Annual Anomalous Absorption Conference
26 June - 1 July 1988, l'Estérel, Québec

Electron Acceleration in a Relativistic Electron Plasma Wave

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The one dimensionnal trajectories of test electrons in a large amplitude relativistic ($v_\phi \approx c$) electron plasma wave are computed both analytically and numerically. The analytical result is related to the relativistic Landau damping. The numerical results enable to determinate the optimum injection energy of electrons in a given experiment. Application to the Beat Wave experiment using the Neodymium glass laser is made.

CO_2 Laser Heated Plasmas for Collisionally Pumped VUV Laser Studies

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We have completed a series of experiments designed to characterize plasmas produced by moderate intensity (~10^{13} W cm^{-2}), nanosecond, CO_2 laser irradiation of foil targets in line focus geometry. X-ray line and continuum diagnostics have been employed to infer a 300 eV heat front that penetrates to depths of 20 μgm cm^{-2} in Al targets. For the case of Cu targets, the observation of L-shell x-ray transitions from Ne-like and F-like ions shows a similar ionization distribution to that observed in 1 μm laser-produced plasmas in which gain has been observed.

Recent modifications to our focussing system have allowed us to obtain a line focus up to 14 mm in length (x 0.15 mm) . Preliminary experiments to characterize the VUV emission from thin Cu foils will be presented and discussed.

17th Anomalous Absorption Conference l'Estérel, Quebec 1988

Diagnostics and Interaction Experiments in long plasmas

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Interaction experiments have been performed in long and homogeneous plasmas to study mainly Brillouin and Raman instabilities.

The plasma is created by irradiation of a thin plastic foil with a first laser beam (λ=0.53μm, τ=500ps, $I \approx 10^{13}$W/cm^2) focused along a 2mm long focus line. The homogeneity of the laser intensity in the focal spot and the homogeneity of the plasma are controlled by X-ray pinhole pictures and visible interferometry. The main laser beam (λ=0.53μm, τ=500ps, $I \approx 10^{15}$W/cm^2) interacts along the homogeneous underdense plasma. We present the analysis of the results obtained from the time-resolved spectra of Brillouin backscattering and forward and backward Raman scattering.

HYDRODYNAMIC INSTABILITIES IN LASER ACCELERATED TRI-LAYER TARGETS.

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Au-Al-Au tri-layer plane targets appear suitable to study the developpement of Rayleigh-Taylor instabilities which arise in laser-driven implosions . Instabilities occur at the rear Al-Au interface of the targets. Small wavelength modes give rise to turbulence and mixing between Al and Au which can be detected by heating up the rear of the target with a probe laser beam : if the thickness of the rear gold layer is greater than the probing beam ablation depth, appearance of Al lines will give evidence of RT instabilities occurence. The front Au layer is aimed at smoothing the energy deposition and prevents direct heating of the Al layer by the main laser beam. Indeed Al lines were observed with both time-integrated and time-resolved spectrographs.

In these experiments, wavelengths of main and probe beams are 0.35 um and 1.06 um respectively. The irradiance is 3.10^{13} W/cm^2 on both sides. A good uniformity in the focal spots is obtained with "random phase plates" (RPP). The Al He emission is measured versus the front laser energy: it seems that this emission has a maximum depending on the target thickness. The simulations show that the radiative preheating from the front Au layer plays an important part in this process. In order to give quantitative estimation of the composition of the mixture we compare the Al He line emissions given by accelerated tri-layer targets with that of unmoved targets composed of calibrated Al-Au mixtures On the other hand the temporal shapes of the Al lines is obtained with a time-resolved spectrograph; it can give important informations about detailed parameters of the mixing zone.

RAMAN SCATTERING FROM A PARABOLIC DENSITY PROFILE

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Recent experiments and theoretical work on stimulated Raman scattering have focussed on long scale-length plasmas created by exploding thin burn-through foils. These result in Gaussian or parabolic shaped profiles having a local density maximum. Smaller scale localized density maxima may also be generated.

The full wave equations describing back and forward Raman scattering have been solved numerically in a parabolic density profile. The global eigenstates obtained include multiple resonances and wave reflections. When the density maximum is below quarter-critical, three absolutely unstable regimes exist. As expected the lowest scattered frequencies emerge from backscattering from the density maximum which has the lowest threshold. This agrees well with that predicted using a WKB analysis.

At higher scattered frequencies the two backscatter resonances occur at lower densities with slightly increased thresholds. At a certain scattered frequency, it is possible to have forward scattering from the density maximum, convective on its own but driven absolute due to seeding by the waves of the backscatter resonances, in themselves exhibiting absolute growth, at slightly lower densities on either side of the density maximum. This back/forward scatter interaction leads to lowered thresholds relative to that for backscatter on its own. For still higher scattered frequencies the forward propagating plasma wave becomes evanescent through the density maximum and hence the four resonances for back and forward scatter on each side of the density maximum are now coupled, less strongly, only through the scattered waves. A three to four fold increase in threshold results.

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Studies of Multi-Photon Ionization at the ANU

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Abstract

During work on multi-photon and tunnelling ionization of atoms in the late 1970's we identified a clear role for the ponderomotive force in determining the energy spectra of the electrons emitted from the ionized volume. More recent experiments elsewhere have revealed additional complexity by demonstrating phenomena that are not easily explained by simple quantum mechanical or classical treatments of the ionization process. The interpretation of energy spectra of the electrons requires a detailed understanding of energy transfer from the laser both due to the ionization process itself and by the conversion of the electron oscillation energy in the laser field to directed kinetic energy as the electron emerges from the beam. In this paper, we present the results of computer simulations of ponderomotive electron acceleration from high intensity, picosecond laser pulses and demonstrate that the final spectrum is a strong function of the beam and pulse parameters which considerably complicate the interpretation of these spectra.

For our experimental work, we are modifying our single beam Nd:glass laser by the addition of a pulse compressor to generate sub-psec multi-TW pulses. Development of a 30psec AMQ Nd:YLF ring laser provides the potential for sub-psec operation of the system. Large area gratings should provide the capability of powers up to 5TW which using our existing F=1 optics should result in focussed intensities close to 10^{20}W/cm^2.

RADIATION PREHEAT AND TRANSPORT STUDIES IN THIN FOIL TARGETS.

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T. Afshar–Rad, S. Rose.
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The transport processes of soft x–ray radiation through thin foil targets were investigated using time resolved XUV spectroscopy. The targets used consisted of thin foil plastic substrates, 0.1 μm to 36 μm thick, overcoated with 1000 Å of gold. The gold was irradiated with a green laser beam 800 ps in duration. The soft x–ray radiation transmitted through the targets was time resolved in the 15 Å to 70 Å spectral wavelength region. For very thin substrate foils, the soft x–rays were not observed to be significantly affected by the foil. However, a clear time delay, particularly towards longer wavelengths, was observed when a substrate foil greater than 3 μm thick was used. Initial modelling of the experimental results has been carried out. Both the experimental observations and the simulations will be presented.

An Overview of Raman Scattering Experiments Using Nova*

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At the completion of the Nova Laser construction project, many observations of Stimulated Raman Scattering(SRS) had been reported in the literature. However, there was little detailed understanding of SRS and no real ability to extrapolate to the conditions anticipated in high-gain, laser-fusion targets. Our goal with Nova was to gain such understanding. We have obtained some measure of success; this talk will describe how we did so.

In early experiments, Nova easily produced the anticipated results for SRS from planar plasmas irradiated with 0.35-um light. SRS yields of a few percent of the laser energy, strong SRS sidescatter, and enhanced SRS from exploding-foil targets all were observed. We also obtained one new result-- forward SRS[1], and one surprise-- the absence of a "gap" in the SRS spectrum under certain conditions.

From this starting point, we devised a scaling experiment[2] that explored SRS in more detail. This experiment allowed us to independently evaluate the scaling of SRS with laser intensity and density-gradient scale length. It depended on several elements: a reasonable understanding of exploding-foil targets, production of flat-topped, kilojoule laser pulses of variable duration, measurements using time-resolved spectroscopy, and absolute measurements of scattered light fluence were all crucial. I will discuss how these elements worked together to produce data that convinced us that SRS is absolutely unstable in these plasmas[3].

I will also direct you to further results discussed at this meeting, including work on collisional damping, evidence suggesting an explanation for the "gap", and a testing of the hypothesis of absolute instability in an experiment using all ten Nova arms.

1.R.E.Turner, et.al., Phys.Rev.Lett. 54, 189(1985)
2.R.P.Drake, et.al., Phys.Fluids, May 1988
3.R.P.Drake, et.al., Phys.Rev.Lett. 60, 1018(1988)

Acknowledgements: This work was a collaborative effort. Peter Young, Ed Williams, Hector Baldis, Kent Estabrook, Tudor Johnston, Chris Darrow, Dave Montgomery, Bill Kruer, Bob Turner, Barbara Lasinski, and Mike Campbell all contributed significantly, as did the scientific and technical staff that develop, operate, and make targets for the Nova laser.
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NONLOCAL EFFECTS AND THE RAMAN INSTABILITY

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The full Raman scattering equations have been solved numerically in linear and parabolic density profiles in an attempt to overcome the local nature of most previous analyses. The code allows for coupling of the back and forward scattering resonances (1) and for wave reflections. This global solution elucidates the transition between absolute and convective instability. It is shown that in the absence of damping, feedback linking back and forward Raman scattering can result in an instability that is absolute at all scattered frequences ω_s, though thresholds are higher than for SRS at the quarter-critical density.

We find that reflection of forward scattered light lowers thresholds and increases growth rates and that thresholds for absolute instability are lowered relative to that predicted by SRS-C theory.

(1) P. Koch and E.A. Williams, Phys. Fluids **27**, 2346(1984)

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Modifications of SRS In A Density Gradient From Coherent Ion Fluctations of SBS*

ABSTRACT

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Observation of Forward Raman Scattering in long underdense plasmas

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One possible mechanism producing high-level electric fields usable for particle acceleration is the forward Raman scattering of a high intensity laser beam in a long and homogeneous underdense plasma.

We present some experimental results obtained in these conditions at the laser facility of the L.U.L.I at Ecole Polytechnique. The plasma is created by irradiation of a thin plastic foil by a first laser beam focused onto a 2mm long focal spot. The main beam (λ=0.53µm, τ=500ps, $I \approx 10^{15}$W/cm^2) then interacts along this homogeneous plasma. Time-resolved spectra of backward and forward Raman scattering indicate the occurence of these instabilities in a narrow range of densities centered at about 5% of the critical density. The main features of the spectra are analysed and compared with existing theories.

Reduction of emitted light at SRS wavelengths to thermal levels by collisional damping*

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Collisional damping has been reported to reduce the intensity of SRS by at least three orders of magnitude in past experiments[1], limited by detector sensitivity. However, the actual thermal noise level is several orders of magnitude smaller. As a result, it was unclear whether the SRS had been fully quenched or merely reduced. If the latter were the case, then then producing larger, longer-scalelength plasmas without substantially increasing the collisionality could lead to markedly increased SRS.

We report an experiment that tested the quenching of SRS by collisions. Thin (0.25-μm and 0.4-μm) gold foils were irradiated with 0.35-μm light in flat-topped pulses by one arm of the Nova laser. The spot size, laser energy, and pulse lengths were systematically varied so as to vary the laser intensity while producing planar plasmas with similar density profiles. The parameters were chosen so that the maximum density of the target plasma dropped to below tenth-critical by the end of the laser pulse, as described previously for CH targets[2]. We obtained time-resolved SRS spectra and time-integrated, absolutely-calibrated SRS fluences when the SRS was intense. In all cases, we obtained time-resolved data from a discrete-channel spectrometer with six channels.

The experiment demonstrated complete quenching of SRS by collisional damping. The magnitude of the emission at the SRS wavelengths decreased by almost 6 orders of magnitude as the ratio of the electron-ion collision rate to the homogenous SRS growth rate increased from 0.25 to 5. In the heavily-damped case, both the absolutely-calibrated spectrum and the time history of the emission showed that the light was thermal emission (or Thomson scattering from thermal plasma waves) and was not produced by SRS.

1. R. E. Turner, et al. Phys. Rev. Lett. 54, 189 (1985).
2. R. P. Drake, et al. Phys. Fluids, May 1988.

*This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

SRS and SBS in Long Scale Length CH Plasmas*

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Abstract

We present the first experimental evidence of modification of the scattered light spectrum of SRS due to the presence of large levels of SBS. The experiment was performed by irradiating CH thin foils with 0.35 μm laser light. The time-dependent scattered spectrum shows the characteristic "gap", with a temporal behavior that can be explained in terms of the observed SBS scsttered light.

The 3 μm thick foils were irradiated using one arm of Nova, with pulses having a rise-time of 100 ps and a flat top to within 20%. The intensity on target was varied between 10^{13} and 4×10^{15} W/cm^2. Temporally resolved SRS and SBS spectra were obtained using spectrograph/streak camera combinations. A third instrument allowed measurement of the Raman light within the gap region with an extended dynamic range.

**Work performed under the auspices of the U.S.Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.*

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Measurements of SRS In Ultra-long Scalelength, Preformed Plasmas On Nova

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We report the results of experiments designed to investigate the scaling of SRS in the largest plasmas attainable with the Nova laser system. The purpose of these experiments was to investigate the scaling of SRS in plasmas whose paramaters approach those anticipated for an ICF reactor target. To this end, nine arms of Nova (4 ns., 18 kJ, .35 μm) were used to irradiate a 15 μm burnthrough CH target to preform a plasma with a calculated axial density scalelength of $L_n/\lambda \sim 3000 - 5000$ and $R_{spot} > c_s\tau$. A tenth beam, delayed by 3 ns. drove the SRS instability at $n_e \sim \frac{n_{crit}}{10}$ with $I_{laser} \sim 1.5 \times 10^{15}$ W/cm^2. Raman light collected by a time resolved spectrometer and filtered, time integrated photodiodes allowed us to determine the contribution to the total Raman signal of the delayed, high intensity Raman driver beam. The measured scaling of the Raman reflectivity as well as pertinent hydrodynamics issues will be discussed.

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Images of Stimulated Laser Scatter

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Plastic (CH) targets were irradiated with unsmoothed and ISI-smoothed 527 nm laser beams. Peak irradiances were 1 to 2 x 10^{14} W/cm^2. Pulse width (FWHM) was 2 nsec. Laser energy and bandwidth were varied. Time-integrated images of the side-scattered $3\omega/2$ (351 nm), back-scattered brillouin (527 nm) and back-scattered Raman (600-700 nm) radiation were recorded on Polaroid positive-negative (type 55) film. Structures are discussed in terms of varying experimental conditions and phenomena such as ISI smoothing or, for unsmoothed beams, possible self-focusing. Correlations with other diagnostics are noted, including the angular, spectral and temporal intensity dependence of Brillouin and Raman scattering.

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OBSERVATIONS OF RAMAN UP-SCATTER IN A LONG SCALE LENGTH PLASMA

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Abstract

We present observations of an enhanced scattering band near $3\omega_O 2$. These experiments were performed on the NOVA laser system operating at 0.351 μm. Nine "heating" beams, each of intensity 2×10^{14} W/cm^2, formed a very long scale length ($L/\lambda_0 \approx 5{,}000$) plasma. The tenth, or "interaction," beam was time delayed relative to the heating beams and was focused to a much higher intensity (2×10^{15} W/cm^2). The interaction beam arrived after the thin (15 μm) CH foil target had become underdense. We attribute this up-scattered band to Thomson scattering of the interaction beam from enhanced electron density fluctuations. We will evaluate the possible sources of this enhancement, including the presence of a beam of superhot electrons. The observed wavelengths will be compared to the enhanced Thomson scattering theory,[1] using values of the background and superthermal electron temperatures inferred from the spectrum of the x rays emitted from the plasma.

1. A. Simon, W. Seka, L.M. Goldman, and R.W. Short, "Raman Scattering in Inhomogeneous Laser-Produced Plasma," Phys. Fluids 29, 1704-1718 (May 1986).

"This work was supported by the U.S. Department of Energy Office Of Inertial Fusion under agreements No. DE-FC08-85DP40200 and by the Sponsors of the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics."

The Effect of Induced Spatial Incoherence on Stimulated Raman Scattering

by

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The Induced Spatial Incoherence ISI method of smoothening of the laser profile is found to have a strong stabilizing influence on the backscattered Raman instabilities from the quarter critical and the underdense plasma[(1)]. In our present study we examine the stimulated Raman instability, by considering a pump which models the effects of ISI. Without ISI, Raman scattering can be induced by hot spots in the laser light, even if the spatially averaged intensity (averaged over the spot size) is less than the inhomogeneity or collisional threshold. With ISI, the spatial smoothening strongly reduces the backscatter if the growth rate γ in the presence of damping or inhomogeneity is less than the laser bandwidth $\Delta\omega$. However for laser intensities much above the inhomogeneity or collisional threshold, ISI does not significantly modify the instability growth rate since $\gamma >> \Delta\omega$.

(1) S.P. Obenchain et al. Phys. Rev. Letts 56, 2807 (1986).

18th Annual Anomalous Absorption Conference
l'Estérel, Québec
26 June - 1 July 1988

ENERGY AND NONLINEARITY CONSIDERATIONS FOR THE ENHANCED PLASMA WAVE MODEL OF RAMAN SCATTERING

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Abstract

In the enhanced plasma wave model of Raman scattering[1,2], pulses of energetic electrons originating in parametric processes at quarter-critical amplify the thermal level of plasma waves, resulting in enhanced Thomson scattering (which may be misinterpreted as SRS). Here we consider the internal consistency of this model. We postulate the creation of a particular set of pulses at $n_c/4$ and then consider subsequent consequences. It is shown that one can meet all obvious limitations on conversion of laser light into fast electrons, energy delivered to enhanced plasma waves, and nonlinear limits on these waves, and still fit all the recent observations on Nova[3]. A simple nonlinear criterion suggests that wave energy has saturated before onset of the SRS instability, as implied by the results in Ref. 3. Recent x-ray spectral analysis on Alcator is also relevant[4]. While the parameters of the model are not uniquely determined, it appears that internal consistency is not a problem for this or all earlier experiments which have been considered.

1. A.Simon and R.W. Short, Phys. Rev. Lett. 53, 1912 (1984)
2. A.Simon et al., Phys. Fluids 29, 1704 (1986)
3. R.P. Drake et al., Phys. Rev. Lett. 60, 1018 (1988)
4. J.E. Rice and K.L. Chamberlin, MIT report PFC/JA-88-2, February, 1988.

"This work was supported by the U.S. Department of Energy Office Of Inertial Fusion under agreements No. DE-FC08-85DP40200 and by the Sponsors of the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics."

Review Talk (45 min)

R2

Abstract for the
18th Annual Anomalous Absorption Conference
26 June - 1 July 1988

The Physics of Beat Excited Plasma Waves

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In this talk I will summarize a series of experiments aimed at elucidating the nature of relativistic plasma waves excited by collinear optical mixing. The excitation of such a wave is detected by ruby laser Thomson scattering as well as by non-degenerate four wave mixing. The latter produces Stokes and anti-Stokes sidebands in the forward direction. In addition, harmonics both spatial and temporal of the plasma wave are seen. The spatial harmonics occur because of wave-wave interaction (mode coupling) between the beat excited plasma wave and an ion acoustic wave from stimulated Brillouin scattering. Harmonics of ion wave are also observed. Recent work has been on wave-particle interaction which is studied in a controlled manner by injecting relativistic "test" electrons. Implications of this work to the beat wave accelerator concept will be discussed.

Work in collaboration with C. Clayton, K. Marsh, W. Leemans, R. Williams, D. Umstadter, C. Darrow, and H. Fiqueroa. Work is supported by DOE contracts DE-AS03-83-ER40120, DE-FG03-87-ER13752, ONR contract NOOO14-86-K-0585, and LLNL University Research Program.

L

Coupled non-LTE Electron and Ion Population Distributions*

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Plasma Physics Division, Plasma Radiation Branch, Naval Research Lab.

In the K-shell, ion excitations that are produced by a depleted tail of the electron distribution function cause reductions in ionization and excitation rates, whose main effect is to steepen the leading edge of the line emission versus temperature curve[1]. In the L-shell, on the other hand, a broader distribution of states than in the K-shell can be affected by non-Maxwellian electrons, and $\Delta n=0$ transitions can be affected by the bulk rather than the tail of the electron distribution. Comparison calculations will be presented showing how laser heating and inelastic collisions in the K-shell of neon and the L-shell of an iron plasma produce non-Maxwellian electron distributions and, reciprocally, how these non-Maxwellian electrons modify the rate coefficients and hence the He-like and H-like ionization stages in neon and ionization abundances of the neon-like through lithium-like ionization stages in iron. The non-Maxwellian distributions are found by solving a Fokker-Planck equation in which the electrons are heated by laser absorption and cooled by inelastic collisions with the K- and L-shell ions. The electron and the ionization calculations proceed self-consistently from a common data base of atomic collision strengths. In particular, we will examine how excited state populations in the neon-like ionization stage are depressed by a reduced number of high energy electrons that result from the laser heating and inelastic collision processes, and we will comment on the effect of these reduced populations on neon-like x-ray lasers.

* Work Supported by DNA

+ Berkeley Research Assoc., Springfield, Va. 22150

1 K. Whitney, N. Pereira, IEEE Intl. Conf. on Plasma Phys. 1987.

Radiation Cooling in Plasmas Containing Layers of High Z and Low Z Materials

J.C. Moreno, S. Goldsmith, H.R. Griem (U. of Maryland),
R. Epstein, J. Knauer (LLE), P. Jaanimagi

Adding a layer of high Z material to a target can significantly influence plasma parameters through fast radiative cooling and transport effects. In this experiment glass microballoons coated with layers of high Z (Cu or Au) and low Z (CH or Al) materials were uniformly irradiated with 24 beams from the OMEGA laser at Rochester. The thickness of the high Z layer was varied and measurements were made of X-ray and XUV emission from the laser produced plasma. Evidence for cooling was observed from line intensity and line ratio measurements. Radiative cooling may be related to mixing of different layers due to Rayleigh-Taylor instabilities and hot spots.

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

D3

Density-gradient effects in the competition between stimulated Raman scattering and stimulated Brillouin scattering

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Abstract

The SATIN code[1] solves a system of fluid coupled mode equations describing the nonlinear coupling of electromagnetic waves, Langmuir waves, and ion acoustic waves in an inhomogeneous plasma. This set of equations includes at least in principle stimulated Raman and Brillouin scattering, two plasmon decay, and Langmuir turbulence. The model equations for the high frequency modes are second order in space and first order in time (a slowly-varying envelope approximation). The spatial derivatives are differenced in the direction of inhomogeneity and Fourier-decomposed otherwise. The ion mode equation, which is second order in space and time, is solved with a second order explicit upwind differencing scheme. The nonlinear terms are treated explicitly.

We report SATIN simulations of the nonlinear evolution of the stimulated Raman scattering and stimulated Brillioun scattering instabilities in a density gradient and compare our results with homogeneous plasma results.[2]

1. L.V. Powers and R.L. Berger, B.A.P.S. 30, 1527 (1985).
2. Harvey A. Rose, D.F. DuBois and B. Bezzerides, Phys. Rev. Lett. 58, 2547 (1987;

   G. Bonnaud and D. Pesme, to be published in Laser Interactions and Related Phenomena, Vol 8.

X-ray Imaging of Radiatively Driven Implosions*

J. D. Kilkenny, F. N. Ze, R. E. Turner, S. P. Hatchett and L. J. Suter

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The continual good agreement between neutron yield measurement of targets indirectly imploded on Nova and Lasnex simulations suggest that we have been achieving near one-dimensional performance from capsules with radial convergence in excess of 30. In this paper we present x-ray images which corroborate the inferred convergences and high degree of symmetry.

Time resolved pinhole camera images were recorded with a four-channel gated microchannel plate. By shot to shot variation of the symmetry of the drive, the image of the compressed core could be made to change from circular to oblate in agreement with two-dimensional simulations.

Hard x-ray, time integrated images over a range of energies were recorded with a pinhole camera and a film pack. By varying the capsule parameters, redial convergence from 15 to 30 were observed. The size and symmetry of the images agrees with simulations.

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

THOMSON SCATTERING MEASUREMENTS OF TEMPERATURE AND DENSITY IN A HOT, DENSE LASER PLASMA

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We have recently used large angle Thomson scattering from thermal plasma fluctuations to measure the electron and ion temperatures in a preformed CO_2 laser-plasma. A single streak camera record of the Thomson scattering spectrum is sufficient to determine the time evolution of the electron and ion temperatures, the plasma density, and the flow velocities of the electrons and ions. Details of previous measurements of low density plasmas ($n_e \sim 10^{18} - 10^{19}$ cm^{-3}) using a 0.532 μm probe will be presented. Higher density, hotter plasmas such as those which are required for x-ray lasers will require a shorter wavelength Thomson scattering probe. The new LP2 Nd:glass laser at NRC is capable of producing such plasmas on a small scale and we are proposing to measure their parameters with a 0.266 μm probe. We will present details of the proposed experiments along with theoretical estimates of the Thomson scattering signal levels and spectra.

Time-Resolved Gating with Microchannel Plates*

R. E. Turner, P. Bell, R. Hanks, J. D. Kilkenny
G. Power, and J. Wiedwald

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We have obtained x-ray pinhole images of imploded ICF targets, with 150 ps time resolution. By using Ar doped fuel and low opacity shells, the actual fuel region is observed. We will also show data which is pertinent to drive symmetry. We will also report on our latest efforts at characterizing the MCP response to short electrical pulses. Gate times of 75 ps FWHM have been measured using a UV dye laser as an excitation source. The spatial resolution of the entire instrument has been measured in situ in the Nova target chamber. We will discuss the applications of time-resolved MCP based instruments to Nova ICF experiments.

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

TIME-RESOLVED X-RAY ALBEDO MEASUREMENTS*

F. Ze, L. Suter, E. M. Campbell, and J. D. Kilkenny

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The x-ray power and spectrum emitted by targets heated by an intesne flux of x rays is of scientific interest for radiation transport and is of practical interest for ICF. We have irradiated gold, aluminum and uranium with x-ray fluxes of 70 eV equivalent temperature and measured the time history of the remission. One or two beams of the Nova laser irradiated a gold disc at laser intensities between 9 x 10^{13} to 5 x 10^{14} W/cm^2. In a square 1 nsec pulses at a wavelength of 0.35 μm. Targets of Al and Au nearby were heated by the x-ray flux from the disc. The time history of the disc emission and the sample's remission were measured with a spatially resolved x-ray streak camera, at photon energies of 500 eV. The disc flux is approximately constant during the 1 nsec square laser pulse. The x-ray re-emission from the Au follows the disc flux, but the remission from the Al increases with time. Comparison with simple view factor and Lasnex calculations will be presented.

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

D8

Modeling Time Dependence and Conversion Efficiency in Gold-Beryllium Disks

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ABSTRACT

In the summer of 1987 we shot a series of gold disks and disks made of a mixture of gold and beryllium using the NOVA laser. This talk summarizes our results and compares them to LASNEX modeling. Many different detectors were used in these experiments. Here we consider only the time integrated conversion efficiencies, the gold M-band spectrum, and the time dependence of the X-rays. We show that LASNEX models do a good job of matching the conversion efficiency both below 1.5 keV and for the M-band. A single set of LASNEX parameters matches the conversion efficiency as a function of laser intensity and of gold concentration for 1 ns laser pulses. The time dependence shows some interesting time lags between the laser intensity and the X-ray intensity, and an increasing conversion efficiency below 500 eV for long pulses. The implications of these time dependent results for our modeling are discussed.

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

<u>Kinetic Simulations of High Intensity Picosecond Laser-Target Interaction.</u>

J.P. Matte, J.C. Kieffer, P. Audebert, M. Chaker, and H. Pépin. INRS-Energie, Varennes, Québec.

Our electron kinetic[1] code has been used to simulate high intensity (10^{16} W/cm^2), short pulse (1 ps. FWHM) laser-target interaction at both 1.06 and 0.26 μm wavelengths. The code includes the effects of advection, an electric field to ensure quasi-neutrality, electron-electron and electron-ion collisions (Fokker-Planck), hydrodynamics and inverse Bremsstrahlung absorption. A simple model of electron impact ionization was also included. An initial density scale-length of 2 μm was assumed, because, in actual experiments, there was a low intensity prepulse. This makes absorption in the overdense (skin depth penetration) negligible. Absorption was only 5% at 1.06 μm, but 30% at 0.26 μm. The electron distribution function deviated strongly from a Maxwellian, due to the extremely steep temperature gradient. The temperature rises to approximately 2 keV at the peak of the pulse, but decreases very rapidly after. This makes picosecond optical pulses a very promising way of pumping X-ray lasers.

1. J.P. Matte, T. W. Johnston, J. Delettrez and R. L. McCrory. Phys. Rev. Lett. 53, 1461 (1984).

D10

RESONANT SELF-FOCUSING IN THE BEAT-WAVE ACCELERATOR

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The colinear propagation of an arbitrary number of finite-amplitude waves is modeled by a system of coupled Schroedinger equations; one equation for each complex wave amplitude. This model incorporates the effects of a coordinate-dependent external potential and arbitrary, coordinate-independent nonlinearities. A virial theorem is derived, which governs the self-focusing of these nonlinearly-coupled waves. For two light waves in a beat-wave accelerator, the coupling to each other and to the resonantly-generated Langmuir wave reduces the threshold power for relativistic self-focusing by an order of magnitude.

Laser-Plasma Instabilities in Large ICF-Related Plasmas: Survey of Thresholds and Simple Target Modeling*

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ABSTRACT

We have checked, updated, and consolidated threshold calculations for Backward and Forward Stimulated Raman Scattering, and Stimulated Brillouin Scattering.[1] These thresholds, plus a simple model for laser light self-focusing,[2] have been incorporated into a simple hydrocode. Using this code, we consider the expected laser-plasma coupling behavior for a number of direct-drive targets.

[1]J. Drake, *et al.*, Phys. Fluids **17**, 778 (1974); D. W. Forslund, *et al.*, Phys. Fluids **18**, 1002 (1975).

[2]R. D. Jones, *et al.*, To be published in Phys. Fluids , and references therein.

*Work supported by U.S.D.O.E.

Physics and Design Issues and Applications for a Proposed ICF Intermediate Driver*

W. C. Mead, S. V. Coggeshall, P. D. Goldstone, R. D. Jones,
A. A. Hauer, G. R. Magelssen

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ABSTRACT

Recently, we have been considering the target physics and design issues associated with a 0.25 μm wavelength ICF laser driver in the multi-hundred-kilojoule range. The general goals of a facility at this size would be (1) to demonstrate advances in driver technology; (2) to study target physics in the near-ignition regime; and (3) to demonstrate adequate driver-target coupling for conditions comparable with those of megajoule reactor targets. We are beginning to examine design options for both indirectly- and directly- driven targets, and will consider whether illumination requirements for both target classes can be adequately met.

We present results of the physics and design studies to date. We show performance predictions for various target types, especially considering near-ignition targets and laser-target coupling experiments. We discuss the new physics and plasma regimes which could be accessed and comment on the expected behavior of various coupling processes. Issues associated with actually achieving ignition are discussed.

*Work supported by U.S.D.O.E.

Multilayer Targets and Direct Drive Laser Fusion

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Multilayer targets have frequently been used for diagnostic purposes and they are now an integral part of most laser fusion target designs. A typical example are cryogenic targets where the fuel layer is frozen out on the inside surface of the target. In all cases one assumes that the layers remain essentially undisturbed until the ablation layer passes through them. The validity of this assumption has recently been challenged by a number of burn-through[1] and implosion experiments at the Laboratory for Laser Energetics at Rochester and elsewhere.

It has previously been shown that some 1.06μm laser light can penetrate the target and damaging it prior to plasma formation on the target surface.[2] We repeated those experiments using 351nm, 0.6ns laser pulses and obtained comparable results. Similarly, burn-through experiments using multilayer targets with Au signature layers overcoated with CH and irradiated symmetrically exhibited anomalously fast burn-through compared with hydrocode predictions.[3] Even peak intensities10 times above the average could not resolve this discrepancy, while thin Al barrier layer delayed the Au signal sufficiently to agree fairly well with code predictions. Implosion experiments at LLE have also frequently shown improved neutron yields for targets overcoated with Al.

We have carried out a number of low-intensity (10^8 to a few 10^{10}W/cm^2) experiments using a 5ns, 1.05μm, q-switched laser to investigate some of the aspects of multilayer targets. The targets (microscope slides) were coated on one side with Al (100Å, 200Å, 400Å, and 700Å) and, optionally, with CH layers (4000 to 6000Å) on the other side. The laser was focused to about 1mm on the target and we measured the incident, transmitted, and diffusely reflected laser light. Without any coatings the glass slides remained undamaged and no transmission or reflection changes were observed. By contrast, a clear and simultaneous threshold was observed in both transmitted and reflected light for the Al coated targets. The rise in intensity near threshold was instrument-limited to ≈1ns with a dynamic range at the jump >100. Peak transmissions occurred usually close to threshold and varied between 1 and 60% depending on the original Al layer thickness (higher for thinner Al layers). Threshold intensities ranged between a few 10^8W/cm^2 for Al to ten times larger for CH layers exposed directly to the laser light. However, CH layers which were protected by ≥400Å of Al did not show any damage within the range of intensities investigated.

Thin Al barrier layers are thus capable of protecting the fragile inside layers of multilayer targets from low intensity laser radiation which would otherwise damage those layers. (Note: the damage threshold of multilayer targets certainly lies below that for the good high power mirror coatings whose damage thresholds are near 10^9W/cm^2.) Furthermore, the transmission and reflection thresholds during the laser pulse are clear evidence of changes in the surface (or bulk) conditions of the multilayer targets during laser irradiation.

Direct-drive laser fusion experiments utilizing multilayer targets with transparent dielectric outside layers may therefore be prone to damage of the inner layers due to light leakage early on in the pulse. Such damage is unlikely to be uniform since the perturbation threshold values probably depend on micro-inhomogeneities or micro-fissures at the layer interfaces or within the layers. Such nonuniformities would most adversely affect high compression experiments with their high uniformity requirements.

In the short run multilayer laser fusion targets may be protected by >400Å Al outer layers, but a more detailed understanding of the formation of surface plasmas during the low-intensity part of sharply rising laser pulses is essential to find the best solution to the light leakage problem.

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*On leave of absence from the Laboratory for Laser Energetics, University of Rochester, Rochester, NY 14623-1299.

[1]LLE Quarterly Report Nr. 34, University of Rochester, 1988.

[2]J.E. Balmer, T.P. Donaldson, W. Seka, and J.A. Zimmermann, Opt. Comm., **24**,109 (1978).

[3]LLE 1987 Annual Report, University of Rochester, 1988.

ENERGY TRANSFER IN THE NLS MODEL OF LANGMUIR TURBULENCE FOR AN INHOMOGENEOUS PLASMA

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Abstract: We address the question of computing the rate of energy transfer between a pump wave and the background plasma in the cases when the pump wave generates Langmuir turbulence through some resonant mechanism (e. g. resonance absorption of laser light in inhomogeneous plasmas).

This situation is modelled by numerical simulation of a Non Linear Schrödinger equation in which we take into account plasma inhomogeneity, Landau damping and a constant source term. The balance between the absorption due to Landau effect in the vicinity of the resonance region and the convection of Langmuir cavitons due to the inhomogeneity is investigated; scaling laws for the absorption rate are given.

Frequency Up-conversion of Electromagnetic Radiation Using an Overdense Plasma

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We investigate the effects of quickly creating a plasma around a monochromatic electromagnetic source wave, on times-scales on the order of a cycle of the wave. It is found that this rapid change in the medium, going from a neutral gas to a plasma, results in an upshifting of the wave frequency. This upshifting of the incident frequency has the added feature that the new frequency is tunable in the sense that it can be varied by changing the plasma density. It is also found that a substantial fraction of the sinusoidal magnetic field associated with the initial wave can be sustained in the plasma as a time independent magnetic field. 1 and 2D computer simulations have been used to study this process in detail, including the effects of finite ionization time. For long ionization times, strong plasma heating results.

This work is supported by DOE contracts DE-AS03-83-ER40120, DE-FG03-87-ER13752, and ONR contract N00014-86-K-0585.

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Enhanced Raman Scattering in a Flowing Plasma

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Abstract

The growth rate for the Raman scattering instability has been found for the case when the plasma flow has a component perpendicular to the wavevector of the pump. Such a configuration allows the pump and the scattered waves to be linearly converted into corresponding longitudinal waves. The linear conversion has a resonant character which results in an enhancement of the growth rate of the parametric process.

STUDY OF SHOCK COALESCENCE IN LASER IRRADIATED TARGETS

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T. Afshar–Rad and S.J. Rose

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Didcot, U.K.

The coalescence of laser induced shocks has been studied by observing the shock breakout on the rear surface of multiple step targets using optical streak photography. The aluminium targets were irradiated with six beams of the Rutherford Appleton Laboratory VULCAN laser using a cluster arrangement. Five of the laser beams, 800ps in duration, were delayed in time (typically by 1 ns) with respect to the first beam to generate a shaped laser pulse. The observations were modelled with hydroynamic simulations. Experimental results and simulations for shaped as well as Gaussian laser pulses will be presented.

Effects of ISI on Raman Emission

S.P. Obenschain, C. K. Manka, T.A. Peyser, K. J. Kearney, A. N. Mostovych, C. J. Pawley, J.A. Stamper and A. J. Schmitt.

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We have studied the effects of ISI beam smoothing[1,2] and laser bandwidth on Raman scattering in laser produced plasmas. Last year we observed reductions in the backscatter when a 1053 nm laser was focused with ISI to intensities near 10^{14} W/cm^2, utilizing laser coherence times t_c as short as 2 psec. To reduce the Raman threshold in those experiments, a second laser beam with a large focal diameter was used to produce a longer scalelength plasma target. We found that, in contrast with studies at other labs, that there was agreement between experiment and theoretical predictions for the convective growth of Raman backscatter. For this 1053 nm experiment, the agreement with theory was obtained by assuming that the Raman instability could "see" the instantaneous nonuniformities in the focal profiles produced by ISI, because the laser bandwidth was smaller than the Raman growth rate. The low Raman backscattering for the ISI beam when compared to the ordinary laser beam was probably due to the suppression of hydrodynamic phenomena such as filamentation that can enhance Raman scattering.

Recently we have extended our expermental studies of Raman with ISI to shorter wavelength (527 nm) and shorter laser coherence times ($t_c < 1$ psec). The laser intensity were varied up to $3x10^{14}$ W/cm^2, with and without a preplasma target. As with the 1053 nm experiments, ISI suppressed Raman scattering. However, the details of the interaction were different. In particular, with the broader bandwidths used in this study, the suppression of Raman was more complete. There was evidence that the laser bandwidth approached and perhaps exceeded the instability growth rates, thus providing an additional mechanism for suppression of Raman scattering. Details on these measurements will be presented.

1. R. H. Lehmberg and S.P. Obenschain, Opt. Commun. 46, 27 (1983).
2. S.P. Obenschain, J. Grun, M.J. Herbst, K.J. Kearney, C. K. Manka, E.A. McLean, A.N. Mostovych, J.A. Stamper, R.R. Whitlock, S.E. Bodner, J. H. Gardner, and R.H. Lehmberg, Phys. Rev. Lett. 56, 2807 (1986).

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

Compression Measurements for Implosions at Nova*

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Recent implosion experiments at Nova have used secondary dt neutrons from pure deuterium fuel as a measure of fuel areal density ($<\rho R>$). Comparison of the final compressed fuel $<\rho R>$ to the initial uncompressed fuel areal density, $<\rho R>_0$, gives a determination of the final fuel density, ρ, and the convergence ratio, $\eta = R_0/R$. Use of this technique will be discussed and results of ongoing experiments to maximize the convergence ratio will be presented.

*This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

MDC:kl 3121G

E3

18th Annual Anomalous Absorption Conference
l'Estérel, Québec
26 June - 1 July 1988

Cryogenic-Laser-Fusion-Target Implosion Studies performed with the OMEGA UV Laser System

F.J. Marshall, S.A. Letzring, C.P. Verdon, R.L. Kremens, S. Skupsky, R.L. Keck, J.P. Knauer, D.K. Bradley, T. Kessler, J.A. Delettrez, H. Kim, J.M. Soures, and R.L. McCrory

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Abstract

A series of direct drive laser fusion implosion experiments were performed on cryogenically-cooled, DT-filled glass microballoons with the OMEGA 24-beam uv (351nm) laser system. The irradiation uniformity of the OMEGA system was enhanced for these experiments by the use of phase plates. Targets consisted of glass microballoons having radii of 100 to 150 μm, wall thicknesses of 3 to 7 μm, filled with DT gas at pressures of 75 to 100 atmospheres. The targets were cryogenically cooled to below the freezing point of DT, in-situ, by an advanced cryogenic laser fusion target system. Targets were irradiated by approximately 1 to 1.2 kJ of uv light in 650 ps pulses. On target non-uniformities were estimated to be 10 to 15% rms. Target performance was diagnosed by a set of x-ray, plasma and nuclear instruments. Typical target performance recorded was of ~ 70% absorption, maximum shell velocities of ~ 3×10^7 cm s^{-1}, thermonuclear yields of 10^6 to 10^8 and final fuel and shell areal densities of 20 to 40 mg cm^{-2}. Fuel densities at the time of thermonuclear neutron production, estimated from measurements of fuel areal density, were in the range 100 to 200 times the density of liquid DT for the optimum targets examined in these experiments. This represents significant progress in the compression of ICF targets by direct-drive laser irradiation.

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l'Esterel, Quebec
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NON-LTE SIMULATION OF TIME-DEPENDENT FEATURES OF X-RAY SPECTRA FROM HIGH-Z TARGETS

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Abstract

The time-dependent behavior of X-ray emission bands observed in a series of 24-beam ultraviolet direct-illumination experiments on the OMEGA laser system using high-Z targets[1] has been simulated using the non-LTE average-ion atomic model developed for the one-dimensional hydrocode LILAC. Comparisons are made with time-resolved spectra obtained from the SPEAXS streaked curved-crystal X-ray spectrograph.[2] The relationship between the temporal profiles of the laser pulse and the emission from M-band transitions is studied, and the crescent shape of the streaked record of the transition bands due to the time-dependent shift of the average transition energies is reproduced. The shape of the M-band streak can be explained in terms of the evolving distribution of ionization species in the plasma.

1. P. Goldstone et al., Phys. Rev. Lett. **59**, 56 (1987).
2. B. Henke and P. A. Jaanimagi, Rev. Sci. Instrum. **54**, 1311 (1983).

"This work was supported by the U.S. Department of Energy Office Of Inertial Fusion under agreements No. DE-FC08-85DP40200 and by the Sponsors of the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics."

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RECENT EXPERIMENTAL MEASUREMENTS OF LASER BURNTHROUGH ON PLASTIC COATED MICROBALLOONS

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Abstract

Laser burnthrough times of spectroscopic signature layers have been interpreted as an indication of incident laser uniformity. We have previously reported results of burnthrough experiments on the OMEGA laser system in which very fast burnthrough times were observed for bare plastic layers.[1] The addition of an outer thin layer of medium-to high-Z material has been seen to significantly increase the burnthrough times somewhat closer to those predicted for the nominal incident laser intensity.[2] Similar experiments have now been carried out with the use of distributed phase plates (D.P.P.s) in the incident beams and these results will be compared with the results of the previous experiments.

1. D.K. Bradley *et al.*, Paper D3, 17th Anomalous Absorption Conference (1987).
2. J. Delettrez *et al.*, Bull, Am. Phys. Soc. 32, 1741 (1987).

"This work was supported by the U.S. Department of Energy Office Of Inertial Fusion under agreements No. DE-FC08-85DP40200 and by the Sponsors of the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics."

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18th Annual Anomalous Absorption Conference
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Theoretical Analysis of Burnthrough Experiments in Targets with Barrier Layers

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Burnthrough experiments have been shown to be sensitive to the uniformity of the laser illumination.[1] In the preceding paper D. K. Bradley *et al.*, have summarized the results of burnthrough experiments and compared then with simulation results. While the results of these experiments can be interpretated in terms of hot spots in the laser beams, they could also be explained in terms of several processes that may give the same signature as illumination hot-spots: pre-pulse, early shinethrough in the transparent plastic, filamentation, and self-focusing of the hot-spots. In this paper, we discuss whether these processes can actually occur. Also, the effect of the x-ray radiation from the high-Z barrier layers is examined.

1) J. Delettrez *et al.*, Phys. Rev. A 36, 3926 (1987).

"This work was supported by the U.S. Department of Energy Office of Inertial Fusion under agreement No. DE-FC08-85DP40200 and by Sponsors of the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics."

PLASMA EVOLUTION IN LASER-IRRADIATED HOLLOW MICROCYLINDERS

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Hollow microcylinder targets, 200-300 μm in diameter, were internally irradiated at $3 \cdot 10^{14}$ W/cm^2 with 1.05 μm/80 ps laser pulses directed through an axial entrance slit. The soft x-ray emission produced in the interior of the cavities was recorded with a streaked x-ray pinhole camera. A Nomarski-type interferometer provided shot-by-shot information on the temporal and spatial growth of the confined plasma. Both diagnostics consistently show plasma collision near the center of the cylinder about 400 ps after the irradiating laser pulse. The early phase, however, is characterized by a concave density profile which could act as a waveguide in an x-ray laser experiment, thereby alleviating the problem of refraction losses. The experimental results are confirmed by a self-consistent Eulerian fluid code which, in addition, reveals the formation of a density hump along the cylinder axis at times around 350 ps.

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Magnetic Pulse Generation by a Combined Scheme of Laser-Irradiation and Laser-Compression

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presented at the 18th Annual Anomalous Absorption Conference
26 June - 1 July, 1988

When a thin flat target connected to an external circuit is irradiated by a focused laser beam, a large return-electron-current arises in the circuit. This scheme is uniquely suitable for the controlled generation of fast-rising magnetic pulses of field strength as high as 10 MG and rise time of the order of $1ns$. The maximum strength of the magnetic field produced in the coil is however limitted by the suprathermal electron current. In order to further enhance the field strength, a new scheme is proposed by J. Seely that combines both the focused laser irradiation and flux compression. In this scheme, the flux is initially induced in a conducting cylinder by a laser beam focused onto the target surface and then the cylinder is imploded by a set of time-delayed laser beams for flux compression. We expect that the proposed scheme will be able to augment the magnetic pulse strength by an order of magnitude because the field strength is inversely proportional to the cross-sectional area of the cylinder. This scheme is analyzed using a simple target compression model and a suprathermal scaling. The results will be presented in detail at the meeting.

EFFECT OF A RANDOM PHASE PLATE ON THE LASER-DRIVEN ABLATION PROCESS

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The uniformity of the laser beams is one of the most important issue for laser-matter interaction and more specially for hydrodynamic-instability experiments. It is known that a "random phase plate" (RPP) smoothes the laser focal spot and improves implosion results /1/; therefore we have compared the laser-driven ablation of a planar target with and without RPP at 1.06um and 0.35um wavelength for 3.10^{13} W/cm$\cdot^{2}$.

Main diagnostics are X-ray pinhole camera and X-ray spectrometer used respectively to determine the mean irradiance and the ablation depth. Indeed we used bilayer targets made of Al coated with different thicknesses of Au. The ablation depth is the Au-thickness for which the Al He line disappears. For the same mean laser irradiance $\langle I \rangle$ the ablation depth is 20% to 30% smaller with RPP than without .

The pinhole pictures on Au show that the X-ray emission is much more uniform with the RPP. The measured FWHM diameter of the pinhole pictures is in good agreement with the diffraction formula: d=1.22\f/D (D is the size of the "patches" on the RPP). Out of the best focus ,the shape of the energy distribution $I_X(r)$ is a non-symmetrical ring but with RPP this distribution is regular and gaussian. Moreover the size of the pinhole picture with RPP does not change over a large range of focal positions.

/1/ Dr NAKATSUKA's Communication at the CECAM Workshop may 1987 (France)

The Effects of Hydrodynamic Flow on Thermal Filamentation*

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Abstract

The presence of plasma flow in the underdense region of laser-plasma interactions has been shown to affect the thresholds and growth rates of ponderomotively-induced laser filamentation[1-3]. However, at shorter laser wavelengths and/or high Z materials, the interaction tends to be more susceptible to thermal filamentation[4]. The magnitude of this potential problem is investigated by deriving the dispersion relation for thermal filamentation in the presence of background plasma flow. Two characteristic regimes are found, depending upon the relative magnitudes of the acoustic speed and thermal conduction speed. Results will be presented showing the effects on thermal filamentation growth lengths as a function of flow velocity, perturbation wavelength, and coupling strengths.

*Supported by Department of Energy

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18 Years of Anomalous Absorption

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OBSERVATIONS OF HIGH DENSITY PLASMAS PRODUCED WITH PICOSECOND HIGH POWER KrF IRRADIATION

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The recently developed high power KrF system at the Rutherford Appleton Laboratory has been used to heat solid targets with laser energies of up to 1 Joule in 3.5 ps. Single shot irradiances of up to 10^{17} Wcm^{-2} were achieved at the target surface. A number of diagnostics were used to investigate the plasmas produced. These included time integrated and time resolved X-ray and VUV spectroscopy.

Fully ionised aluminium plasmas were observed, and densities well above 10^{23} cm^{-3} were inferred from observations of Stark widths and continuum lowering when the ASE prepulse was less than 10^{-5}. In contrast, when the prepulse level was large, the X-ray spectra indicated an electron density of about $3x10^{22}$ cm^{-3} The production of superthermal electrons above 4.5 keV was studied on bare and plastic coated titanium targets by observing T_iK_α emission. From the intensity of the K_α signal, it was found that about 20% of the incident laser energy was deposited in hot electrons.

Detailed hydrodynamic simulations were carried out to predict and analyse the observations. Both the experimental measurements and simulations will be discussed in the presentation.

ELECTRON NON-LINEARITIES IN LANGMUIR WAVES WITH APPLICATION TO BEAT-WAVE EXPERIMENTS

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ABSTRACT

Non-linear Langmuir waves are examined in the context of the beat-wave accelerator. With a background of immobile ions the waves in one dimension are subject to the relativistic non-linearity of Rosenbluth and Liu (1972). In two or three dimensions, other electron non-linearities occur which involve electric and magnetic fields. The quasi-linear equations for these non-linearities are developed and solved numerically in a geometry representative of laser-driven beat waves.

Static Plasma Density Modulation for a Laser-Plasma-Accelerator

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In one laser-plasma-accelerator scheme, laser radiation incident on a static density modulation produces plasma waves which may accelerate charged particles. A technique to produce the static modulation is experimentally investigated. A ruby laser pulse is focussed to a line on a grating made of alternate lines of low Z* (Photoresist) and high Z* (gold) material. The plasma expanding from the surface is observed using shadowgraphy and interferometry. Density modulations of up to 10% are observed for durations as long as 15 ns after the laser pulse. Grating spacings from 6 μm to 20 μm are used.

CO_2 laser radiation incident on such a plasma with modulation smaller than 10.6 μm creates plasma waves with phase speeds smaller than the speed of light which accelerate charged particles. Experiments to detect the waves using Thomson scattering and actual acceleration of injected electrons are in progress.

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The Modulational Instability and its Consequences for the Beat Wave Accelerator

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The modulational instability caused by the coupling of a Langmuir wave to the ion motion is investigated in the domain of large $v_{osc}/v_{te} < 1$ ratios, where v_{osc} and v_{te} denote the pump Langmuir wave quiver velocity and the electron thermal velocity respectively. A convenient approximate expression for the growth rate is given for $v_{osc}/v_{te} < 50\ (A/Z)^{1/6}$. The limitation of the beat plasmon growth due to the modulational instability is studied in the context of Plasma Beat Wave experiments and the maximum beat plasmon amplitude is determined numerically.

Cascade Focussing in the Beat-Wave Accelerator

P. Gibbon and A.R. Bell (Imperial College)

The wave-envelope equations for the Beat-Wave / Cascade system are studied analytically and numerically in two dimensions. An expression for the mean-square width of the cascade envelope is derived, and is used to predict the long-term behaviour of the waves for various initial conditions. To test these predictions, we solve the equations numerically using an initial value code.

We find that the amplitude of a resonantly driven plasma-wave falls significantly over a stage length due to enhanced diffraction through cascading. Conversely, detuning the pumps from the plasma frequency can lead to focussing of the cascade envelope and a corresponding increase in plasmon amplitude of up to 200% over the same distance.

This work is supported by the UK Science and Engineering Research Council, grant number 85700588.

ABSTRACT FOR THE 18th ANOMALOUS ABSORPTION CONFERENCE
Esterel, Québec
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AIRY ACCELERATION: HOW TO GET 2 MeV ELECTRONS FROM THE C/$\sqrt{3}$ PHASE VELOCITY WAVES AT $n_C/4$*

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The fast electron jet parallel[1] to the laser axis from thin carbon targets correlates positively with light emitted at half the laser frequency ($n \sim n_c/4$) and negatively with light at 80% of the laser frequency ($n \sim n_c/25$). The problem is that the plasma wave phase velocity at $n_c/4$ (namely $c/\sqrt{3}$) is far too low to accelerate electrons up to 2 MeV energies. The answer appears to lie in the plasma inhomogeneity and the Airy-like plasma wave pattern it produces. The recent evidence for this will be presented, together with computational results for particle acceleration in Airy-like fields.

1 S. Aithal et al. Phys. Fluids 30(12), 3825 (1987).

* Ce travail est supporté par le Ministère de l'Education du Québec et par CRSNG Canada.

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TWO-DIMENSIONAL HYDRODYNAMICS AND REFRACTION IN X-RAY LASER EXPERIMENTS

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Abstract

X-ray laser gain due to collision excitation has been observed in line-focus experiments at Livermore and NRL from both exploding-foil[1, 2] and solid[2] targets. Crucial to the interpretation of both experiments is an understanding of x-ray refraction in the plasma profiles, as has been clearly pointed out by London.[3] We have calculated two-dimensional electron density profiles corresponding to both experiments using the hydrodynamics code SAGE, verified that they are reasonable in comparison with interferometry experiments carried out at KMS in collaboration with Livermore,[4] and traced x rays through these profiles following their trajectories in three dimensions. Using simple models for gain profiles in the plasma we can identify the regions likely to produce dominant contributions to the observed gain.

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4. G. Charatis et al., J. de Physique, 47, C6-89 (1986).

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Heated Electron Distributions Resulting from Optical Field Induced Ionization

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It has been proposed that cool dense plasmas for recombination type XUV lasers might be produced by optical field induced (multiphoton) ionization of high Z gases[1]. The phenomenon of above threshold ionization (ATI) will determine the free electron energy distribution and hence the viability of this approach to XUV lasers. Heated electron distributions predicted by quantum non-perturbative theories will be discussed and compared to the results of a simple quasi-static model. It will be shown that ATI presents no unsurmountable obstacle to the production of sufficiently cool plasmas for recombination lasers in the XUV region. Required laser intensities for ions of interest will be shown to be compatible with near term optical drivers. The general phenomenon of ATI in the high intensity-long wavelength limit can be a noteworthy anomalous absorption mechanism for short pulse ultra high intensity lasers.

1 J. Peyraud and N. Peyraud, J. Appl. Phys. 43, 2993 (1972).

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Interaction of psc Pulses with Solid Target at High Intensities

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We have used the well characterized "table top terawatt" laser of the laboratory for laser energetic which delivers on target 250 mJ at $\lambda \simeq 1.06$ µm and 100 mJ at $\lambda \simeq 0.53$ µm. The FWHM of the pulse is 1 ps. The extended pulse shape is measured in detail by using third order correlation function of the laser pulse. The pulses are focussed by a f/8 spherical lens to on intensity exceeding 10^{16} W/cm^2. The focal spot is measured with X-ray pin-hole camera.

The absorption is measured for various angles of incidence with an integrating sphere. The reflectivity is also measured at various angles. The absolute value of the X-ray emission is obtained by deconvolving the data (i) of a soft X-ray spectrometer with filters and diodes and (ii) of a transmission grating spectrometer. The XUV high resolution spectra are taken with a 1 m Rowland circle grazing incidence grating spectrometer. A flat crystal spectrometer is also used to record the keV spectra.

Results indicate that the absorption is relatively important (20% - 40%) at high intensities (10^{14}-10^{16} W/cm^2). Polarization, incidence angle and Z dependence will be discussed. The X-ray conversion efficiency remains constant at high intensities and drops drastically as $I^{1.7}$ for $I < 5.10^{14}$ W/cm^2.

At high intensities and $\lambda = 1.06$ µm, there are fast electrons particularly when the target is tilted respective to the incident beam. But the level of fast electrons and keV emission do not depend clearly on the laser polarization. The X-ray spectra indicate that the emission is coming from a highly ionized expanding plasma at densities close to 10^{21} cm^{-3} and temperatures of 200-400 eV. Spectroscopic studies taken with spatial resolution irradiation are in progress.

Experimental Study of 20 ps Laser Produced Plasmas

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a) National Research Council, Canada.
b) University of Leicester, U.K.
c) Rutherford Appleton Laboratory, U.K.
d) Royal Holloway and Bedford College, U.K.

Abstract

Studies of energy deposition of 20 ps laser pulses have been performed using the new short pulse capability of Vulcan at the Rutherford Appleton Laboratory. These plasmas are of interest in the context of x-ray lasers using recombination schemes, and as intense sources of incoherent x-rays of short duration.

The experiments were performed with laser pulses of either 0.53 or 0.35 μm, and with energies up to 10 and 4 J respectively. Maximun irradiation on target was up to 3×10^{16} Wcm^{-2}. The targets were multi-layer lollipops with buried layers of KCl and CaF_2 and Al under CH ablator and with CH spacer layers. The fraction of energy deposited was estimated from the K_α emission induced by energy deposition from high energy electrons. Electron densities of up to 10^{23} cm^{-3} have been estimated from the Stark broadened profiles of aluminium hydrogenic and helium-like emission lines.

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Interaction of Intense Femtosecond Laser Pulses with Matter

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fs laser pulses of moderate energy are already capable of producing hot high-Z plasmas of solid state density and electron concentrations which exceed those of good electrical conductors by at least one order of magnitude. By using a Thomas-Fermi approach the ionization degree is studied as a function of temperature and atomic density.

The absorption of laser light in the highly overdense plasma constitutes a problem of central importance. Collisional energy dissipation has to be re-examined since in the strong laser field the electron drift velocity is no longer neglegible in the electron-ion collision frequency. Relevant parameter ranges exist in which the drift motion completely dominates the thermal motion. For this limit we calculate the collisional absorption coefficient and, by extending this to zero frequency, we obtain the correct electron-ion collision rate for the dc case. Deviations by factors of several units from the familiar standard results are obtained. The shielding, rather than following the exponential Debye shape, assumes the form of an inverse power law.

Owing to the high electron density the laser field becomes strongly evanescent. As a consequence, the faster electrons in the thermal distribution are subject to a dc rather than an ac laser field which leads to a current density change and to a significant anomalous skin effect.

Review Talk (45 min)

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Anomalous Negative Absorption:
Plasma and Atomic Physics Issues in Laboratory X-Ray Lasers

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ABSTRACT

Laboratories around the world are producing plasmas with atomic population inversions (negative absorption media) that are exhibiting gain at increasingly higher frequencies, approaching the so called "water window" at 22-44Å. Each success is often accompanied by anomalies, which are the focus of this review.

These plasma gain media exhibit many of the instability phenomena familiar to the ICF community. These include Raman scatter which we use to infer T_e and n_e, and possibly filamentation, radiational instability, and ion acoustic turbulence all of whose resultant nonuniformities can seriously affect the x-ray laser beam's propagation and achievable gain-length product.

Current anomalies in gain may be attributable directly to uncertainties in atomic physics or to uncertainties in plasma conditions which in turn affect the atomic physics. In high Z Ni-like systems accurate calculations of radiative cooling are crucial in correctly determining T_e. In short pulse (10 ps) rapid cooling recombination systems, a host of coupling and hot electron issues come into play. Experiments to be performed at NRC and KMS are expected to play a critical role in resolving some of these issues.

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SURVEY OF RECENT KMS GOLD DISK EXPERIMENTS

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Square and picket fence laser pulses ($\lambda = 0.53\ \mu$, $\tau_L = 1\text{-}2$ ns, $\varepsilon = 100 - 200$ J, $I = 10^{14} - 6 \times 10^{14}$ w/cm^2) were used to illuminate gold disk targets (diam = 600 μ, thickness = 22 μ). The target plasma was characterized by imaging both hard and soft xrays (pinhole cameras, streak camera, KB microscope) and by optical measurements (3/2 ω emission, 2 ω emission, holographic interferometry). The energy in both hard and soft xray was also measured. A comparison of the plasma profile and emission for 1 ns and 2 ns square and 2 ns picket fence pulses with both 200 μ and 500 μ spot sizes will be made.

PULSE LENGTH DEPENDENCE OF X-RAY CONVERSION EFFICIENCY*

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Future Inertial Confinement experiments on the Nova laser will require laser/x-ray pulses larger than 1 nsec to drive the implosions. An experiments was performed to explore the effects of long laser pulses on the conversion of laser light to x rays. We have measured the time- dependent and time-integrated x-ray conversion efficiency from gold disk targets as a function of laser pulse length. All of these experiments were performed using one arm of the Nova laser with 0.35 μm light. The laser energy on target was in excess of 1900 J and was focused to approximately 5 x 10^{14} W/cm^2. The temporal profiles of the laser pulses were nominally flat topped and up to 4 ns long. The incident laser power as a function of time was determined from streak camera measurements of the incident 1.06 μm laser light which was cross-calibrated to direct measurements of the 0.35 μm frequency converted laser light in a separate calibration experiment. The total time integrated x-ray yield was measured with a filtered x-ray diode array and the time resolved soft x-ray emission with a multichannel x-ray streak camera and transmission grating streaked spectrograph. Our data indicates that the time-dependent x-ray conversion efficiency increases significantly during the laser pulse. The time-integrated measurements as a function of pulse width are in agreement with this trend. Preliminary results of the x-ray conversion efficiency with shaped laser pulses will be presented.

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

X-Ray Emission From Gold: Beryllium Mixtures*

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In an effort to experimentally address the effects of material opacity on the interaction of 0.35 μm laser light with high z materials and the conversion of the laser light to x rays, an experiment was designed to vary the number density of the high z radiating atoms by controlling the target constituents. In the present case, gold was diluted with beryllium in the target. Disc targets were irradiated at 4×10^{14} W/cm^2 with 1 ns pulses of 0.35 μm light from a single arm of the Nova laser. The targets irradiated were pure Be and pure Au in Be. A strong nonlinear relationship between gold fraction and x-ray production for thermal x rays and gold M-band radiation was observed in the experiments. We present our results and comparisons to computer models of these experiments.

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

Measurements of Plasma Conditions in Exploding Foil X-ray Laser Amplifiers*

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We have been attempting to measure plasma conditions such as electron and ion density, electron temperature as well as ionization balance for laser-irradiated exploding foil amplifier designs. We will report on the measurements done to date and we will describe some future plans for experiments to obtain parameters as yet unmeasured. We will also compare measured with calculated values. Finally, we will describe the effects of these parameters on x-ray laser performance.

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

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Space-, Frequency-, Wavenumber- and Time-Resolved Images of SRS and SBS in a Preformed Plasma

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Thomson scattering techniques were used in our preformed plasma in order to study the evolution of SRS and SBS in time. The Thomson scattered 532 nm probe light was split into two wavelength bands, corresponding to ion waves and plasma waves, before being imaged into a streak camera. By imaging either the target plane or the collection lens plane, space- or wavenumber-resolved images of both types of waves were obtained simultaneously.

The streak photographs showed that the SRS plasma waves appeared early in the interaction, lasted for less than 100 ps, stopped abruptly, followed by the onset of SBS. This observation is in reasonable agreement with the model of Rose, DuBois and Bezzerides[1] for the competition between SRS and SBS.[2] Furthermore, by adding a weak counterpropagating pump pulse, it was possible to totally suppress the appearance of the SRS.

A second streak camera, operating in framing mode, was used to obtain $\omega - k$ images of both types of waves, but without time resolution. This diagnostic clearly showed the harmonics of plasma waves $(l\omega_p, mk_p)$, where ω_p is the plasma frequency, $k_p \approx 1.7k_0$ is the SRS plasma wavenumber, and l and m are integers. Frequency harmonics $(l = m > 1)$ show the presence of wave steepening, and wavenumber harmonics $(l = 1, m = 2, 3)$ indicate coupling between the SBS ion wave and the SRS process.

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2. D M Villeneuve, H A Baldis and J E Bernard, Phys Rev Lett **59**, 1585 (1987).

X-Ray Conversion of 0.35 μm light from Uranium Disk Targets*

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We have measured x ray production from uranium targets from a single arm of the Nova laser. Uranium with a 5% niobium mixture for stability were irradiated with up to kJ of 0.35 μm light in a 1 ns square pulse. Incident laser intensity was varied from 5×10^{13} to 4×10^{15} W/cm^2. Absolute x-ray spectra were measured at energies <1.5 keV using an x-ray diode array and energies > 1.5 keV using x-ray crystal spectrographics. Results and comparisons with previous Au experiments will be presented.

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Modelling of Gold Dot Irradiations*

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As part of our ongoing study of the energy balance in the laser-plasma interactions of gold targets, we have performed experiments with 500 Å thick gold dots embedded in CH irradiated by a 2 kJ, 2 ns pulse of blue light. Time and spatially resolved x-ray diagnostics are the main instruments for monitoring the gold expansion. These results are compared to 1-D and 2-D LASNEX modelling. The onset of the M-lines, 2.0 – 2.8 keV, is calculated correctly with our nominal gold disc model. The subsequent evolution of the M-line emitting region as well as the behavior of the N-lines will be discussed.

* 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.

X-Ray Spectroscopy of Laser Produced Plasmas Using a Transmission Grating.

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Laser produced plasmas are characterized in the 0.10-2.0 keV region. They are produced using either a high energy, λ = 1.06 μm, 3 ns pulse solid state laser or a low energy, λ = 0.249 μm, 20 ns pulse excimer laser. Spectroscopic resolution is achieved with a free-standing transmission grating for dispersion and Kodak-101 film as the detector. These measurements are correlated with those from XRD and PIN diodes equipped with appropriate filters. The resulting spectra are compared to the corresponding spectra predicted by the theoretical model (XSOURCE). This diagnostic allows the measurement of spectral intensity, conversion efficiency and physical characteristics of the source.

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Self-Focusing in long Scalelength Plasmas

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Two-dimensional hydrodynamic simulations of self-focusing in long scalelength (>1cm) plasmas are examined. Some of the factors affecting the space-time evolution of small scale filaments ($\leq 75\mu$m radius) are considered. In particular, diffraction, temperature effects, and the role played by ponderomotive forces, are investigated. The behaviour of self-focusing in the presence of an incoherent laser beam and in a plasma with an initial flow velocity is also considered.

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Simulations and Analysis of a Recent Spherical X-Ray Conversion Efficiency Experiment*

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We present an analysis of X-ray conversion efficiency data taken at the Rochester Omega Laser in late 1987. The targets were illuminated in spherical geometry with ~1.5 kJ at 0.35 μm with a 600 ps FWHM Gaussian pulse. Targets of various Z's were used, including Au, U, and Bi. Laser intensities varied from mid 10^{13} to mid 10^{15} W/cm^2. We present LASNEX simulations of the X-ray spectra for various targets and make comparisons to the present and past data.

*Work supported by U. S. D. O. E.

OBSERVATIONS OF SYMMETRY-, DENSITY-, AND Z-DEPENDENCE OF X-RAY CONVERSION

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Previous measurements of x-ray conversion physics using spherical gold targets irradiated by the 24-beam, 351-nm Omega laser[1] showed high x-ray conversion efficiencies for high-energy, 24-beam irradiations, but x-ray spectra that were significantly different from calculations. In addition, low-energy, 6-beam experiments showed reduced x-ray conversion as compared to higher-energy, 24-beam experiments at the same intensity.

We report here on a recent high-Z plasma dynamics experiment performed at Omega. In this work we assessed the effects of symmetry (uniformity) versus target size on x-ray conversion, and investigated whether x-ray conversion could be improved by optimizing target atomic number or reducing its initial density. In addition we have attempted to obtain more detailed atomic physics information through time-integrated and time-resolved spectral measurements on Au, Bi, and U targets.

Initial analysis of the data indicates that uniformity of irradiation, rather than the target size and energy scale of the experiment, was predominantly responsible for the low x-ray conversions in the previous 6-beam experiments. The addition of distributed phase plates did not significantly change x-ray conversion or soft x-ray spectra as compared to nominal 24-beam Omega irradiation. Changing the density of gold to a few percent of normal also had little effect on x-ray emission. We will discuss these and other results with emphasis on initial analysis of sub-keV x-ray spectra and broadband, absolute x-ray emission measurements.

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18th Anomalous Absorption Conference L'Estérel (Quebec) 1988 June 26 - July 1

Stimulated Raman Scattering (SRS) and ion-sound wave dynamics in inhomogeneous plasma

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The interplay between SRS and ion-sound wave dynamics is investigated in an inhomogeneous plasma with a linear density profile. Simulations have been performed with a wave-like equation coupling code (CHEOPS) which describes SRS, stimulated Brillouin scattering (SBS) and the non-linear coupling between the electron plasma waves (EPW) and the ion sound waves. The Landau damping on EPW is modeled such as to take into account the space dependence of the EPW phase-velocity caused by the plasma inhomogeneity. The modifications due to the finite density-gradient scale-length are studied and compared to the results given by similar studies performed for an homogeneous plasma [1,2]. The lower threshold for SBS regards to SRS enforces SBS during the early times of the laser pulse.

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TRANSIENT STAGE IN THE NONLINEAR EVOLUTION OF THE PARAMETRIC INSTABILITIES

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The SRS and SBS instabilities are investigated in the limit of the envelope approximation for a three wave coupling. The space and time nature of the thermal noise emission is explicitly taken into account. The characteristic time of the transient regime during which the transmission and reflectivity exhibit a chaotic-like behavior is estimated. Scaling laws for the transmission and reflectivity are derived as a function of the thermal noise level.

Four-Wave Mixing and Phase Conjugation in a Plasma with Density Fluctuations*

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Four-wave mixing (FWM) and phase conjugation (PC) have been demonstrated at optical frequencies with various nonlinear media. In such processes, two electromagnetic pump waves ('forward' and 'backward') plus a 'probe' electromagnetic wave interact through the nonlinear low frequency susceptibility of the medium to produce a fourth 'signal' or 'conjugate' electromagnetic wave. Recent calculations [1,2,3,4] have indicated that plasma can be an effective medium for extension of these processes for the infrared to microwave portion of the electromagnetic spectrum. The calculations presented so far have assumed the ambient plasma to be homogeneous and time independent. We include here the effects of small amplitude density fluctuations on PC and FWM in an otherwise homogeneous plasma. For the case in which the fluctuation wavelength is long compared to the wavelength of the pump fields, their principal effect is to decorrelate the relative phases of the pump fields and consequently to increase the gain length. In the opposite limit of short fluctuation wavelengths, their predominant effect is to enhance the decay rate of the induced, low frequency density wave. If the fluctuation wavelength is comparable to that of the beat wave, the fluctuations act as an incoherent component of the conjugate wave intensity.

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Abstract for the
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Wavebreaking of Relativistic Plasma Waves in a Thermal Plasma

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An expression for the maximum amplitude of relativistic plasma oscillations (phase velocity v_{ph} near the speed of light) is obtained with a combined one-dimensional waterbag and warm fluid model. The waterbag description is used to obtain expressions for the pressure $\overline{p}$ and internal energy $\overline{e}$ as function of the proper density. These expressions are substituted into the energy-momentum tensor and the resulting conservation laws of energy and momentum are obtained. Combining these with the waterbag expressions for $\overline{p}$ and $\overline{e}$ gives a form of the relativistic Euler's equation that is valid for arbitrarily large amplitudes. Manipulating these equations along with Maxwell's equation gives an analytic expression for the wavebreaking amplitude in the $v_{ph} \cong c$ limit. The presence of even a small amount of thermal energy can significantly reduce the maximum plasma wave amplitude relative to the cold wavebreaking value. The significance of the results for recent accelerator schemes is discussed.

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Acceleration of Electrons in an Underdense Plasma Containing Fluctuations of Magnetic Field on a Background Large Scale DC magnetic Feild

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Abstract

It is shown that scattering of electrons off magnetic field fluctuations can result in acceleration of these electrons along the lines of force of a large-scale background DC magnetic field. The mechanism proposed is applied to the underdense corona of a laser produced plasma.

Experimental Evidence for Nucleation and Collapse of Langmuir Cavitons in the Interaction of High Frequency Radiation with Plasmas

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Chaos and Soliton Formation during Nonlinear Resonace Absorption in Inhomogeneous Laser produced Plasmas

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The process of resonace absorption at the critical surface in laser produced plasmas can be modeled by the Nonlinear Schrödinger Forced equation($NSFE$)[1],

$$[i\frac{\partial}{\partial t} + x - \frac{\partial^2}{\partial x^2} - p\,|A|^2]A = 1$$

p > 1.250 chaotic

1.088
1.158) period doubling

This equation is derived assuming that the nonlinear time scale is much longer than the plasma period and that the ion acoustic wave is subsonic to justify the quasistatic approxmation.

p = Pond. force / force

The above equation has been solved numerically by a splitting scheme.

A single soliton solution is obtained for small P. As the parmeter P is increased, two soliton soutions, referred to as breather, appear. The interplay between the breather oscillation frequency and the convection frequency as P increases leads to bifurcation from periodic, quasiperiodic to chaotic behavior of the wave amplitude. The absorption rate of the laser light turns out to be sensitive to the nature of the attractor.

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SIMULATIONS OF ULTRA-STRONG LANGMUIR TURBULENCE IN OPEN SYSTEMS

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Langmuir collapse has been shown to be an important effect in laser-plasma interactions, e.g., the case of interacting Raman and Brillouin instabilities.[1-6] The so-called "Zakharov-type" descriptions[1,2] of this effect can breakdown when field amplitudes assume moderate to large values during collapse.[4] We have described "Ultra-Strong Langmuir Collapse" in this regime by a full two-fluid model[4], with none of the attendant difficulties imposed by the usual assumptions in the Zakharov description. A numerical implementation of this model (ESHYDRO) has been modified to include phenomenological damping and model drivers. Simulations demonstrate the onset of the modulational instability, the formation of solitons and their subsequent collapse, followed by burn-out and nucleation events. Density depletions of over 50% and very intense events ($|E|^2/4\pi nT >> 1$) are recorded and easily followed by this code. The onset of wavebreaking is also indicated. Comparisons with the Zakharov model demonstrate the importance of the finite pressure term, and indicate a range of validity for reduced descriptions. Extensions of this model and applications of the results obtained are discussed.

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Heating of electrons by localized Langmuir waves

(Beyond the ponderomotive potential approximation)

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We continue our studies[1,2] on electron heating by localized Langmuir fields. The long wavelength plasma waves, produced for example by stimulated Raman scattering, can be modulated and form localized structures due to ion waves (produced by stimulated Brillouin scattering or parametric decay) or due to modulational instability. The ponderomotive potential plays a fundamental role in the description of a localization process. We examine limits of validity of ponderomotive approximation from the point of view of particle dynamics. The threshold value of the field intensity is given for which regular particle orbits corresponding to ponderomotive potential, become locally unstable leading to rapid particle heating. The heating process is very effective because it involves the bulk of electrons. Evolution of the distribution function is also examined.

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Excitation of Strong Langmuir Turbulence in HF Heating of the Ionosphere*

by

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On the basis of theoretical arguments and long-time solutions of the Zakharov model of strong Langmuir turbulence, we have reached the following conclusions concerning O-mode, HF heating of the ionosphere:

1. The linear parametric instabilities play a role only in the first few ms after the the turn on of the heater in a quiescent ionosphere; 2). These instabilities generally saturate by Langmuir collapse; 3). The resulting turbulent state is sustained by the local nucleation of collapsing cavitons and not by the linear instabilities; 4). The incoherent scatter radar (ISR) measurements of the electron density fluctuation spectra[1] can be explained in detail on the basis of a nucleation-collapse - burnout model of caviton dynamics and by direct numerical solution; 5). This model also agrees with the altitude dependence and the (limited) amgular dependence of the ISR data; 6). Hot electrons observed in airglow are a natural consequence of the burnout following collapse.

1 David Russell, D.F. DuBois and Harvey A. Rose Phys. Rev. Lett. 60, 581 (1988)

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Almost Degenerate Four-Wave Mixing*

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We investigate the theory of degenerate[1] and doubly degenerate[2] four-wave mixing in laser-produced plasmas. By probing the low-frequency dielectric function, this technique has the potential to measure such plasma properties as density, ionization state and temperature. We extend existing theory[1,2] to include the crucial effects of plasma inhomogeneities, and to analyze transient effects excited by short (10 ps) probe laser pulses.

An experimental program has been planned to investigate these phenomena.

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Experimental study of filamentation in laser-produced plasmas

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Abstract

Filamentation is studied in a laser-produced plasma by irradiating a preformed plasma with a laser beam whose spatial profile is intentionally modulated. The modulation is produced by interfering the beam with itself to produce a linear fringe pattern. The spacing of the fringes can be varied from shot to shot to compare experimental thresholds with theoretical predictions as a function of the intensity perturbation wavelength. An optical probe beam is aligned parallel to the fringes and parallel to the target surface to detect the density perturbations produced when filamentation occurs. The experimental design allows us to systematically vary the perturbation wavelength, the filament-driving beam intensity, and the plasma density and temperature. Initial results using the Phoenix laser and CH thin foil targets will be reported.

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THE EFFECT OF SELF-FOCUSING ON HOT SPOTS IN MULTIPLE-BEAM ILLUMINATION GEOMETRIES

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Abstract

Successful direct-drive laser fusion depends on achieving a high degree of uniformity in the illumination of the target. Uniformity can be improved by increasing the number of beams used to drive the target; alternatively, in the random phase mask approach[1], each laser beam is divided into many "beamlets" which overlap when focused on the target. The overlap of many randomly phased beamlets gives a smoother large-scale intensity distribution. Locally, however, constructive interference of groups of beamlets which happen to be in phase at a particular point results in many small-scale hot spots.

Here the effect of ponderomotive self-focusing on these hot spots is investigated. The self-focusing mechanism couples the beamlets, transferring energy between them and thus altering the hot spot intensities. This effect is studied using a simple model of beam interaction; results concerning the magnitude of the hot spot intensity variations and the consequences for uniformity will be presented.

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Measurements of Ion Acoustic Parametric Decay Instability*

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Detailed measurements of the ion acoustic decay instability (IADI) are presented for irradiation by 1 μm and 1/2 μm laser light. Above a well-defined threshold power, the Stokes mode (IADI) is clearly observed in the second harmonic spectrum. The IADI intensity I_{IADI} increases strongly with laser intensity I_L; $I_{IADI} \propto I_L^2$. We are investigating the scaling of the Stokes signal with laser wavelength, plasma scale length, and target material. The measured IADI threshold is fairly low (2 ~ 3) x 10^{13} W/cm^2 for 1 μm, and 1/2 μm lasers. The IADI signal increases with increasing plasma scale length. The IADI threshold also increases for smaller plasma scale lengths. The IADI signal is stronger for lighter target materials. For high Z targets, the IADI signal is fairly symmetric in time. For lower Z targets, a turbulent like Stokes spectrum is observed for intense laser irradiation, and the IADI signal decreases strongly with time.

Our results indicate that the IADI is potentially important in laser-pellet interactions. The experiments are performed using the Janus (Phoenix) laser at LLNL, and the GDL and the Omega lasers at LLE.

* The research and materials incorporated in this work were partially developed at the National Laser Users Facility at the Laboratory for Laser Energetics, University of Rochester, with financial support from the U. S. Department of Energy under Cooperative Agreement DE-AS08-87NV10652.

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Effects of ISI on Stimulated Brillouin Scattering

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The effects of spatial and temporal incoherence on stimulated Brillouin scattering is studied in laser produced plasmas. In previous experiments[1] at the .5μm and 1μm laser wavelengths we observed complete suppression of SBS when using ISI[2] smoothed laser beams. The quenching of SBS was observed even when the laser coherence time was much larger (10x) than the predicted convective saturation time of the instability.

We present the results from more recent experiments where we have measured SBS growth under conditions designed to turn SBS on, even with ISI illumination. The threshold for SBS was lowered by the combination of a second laser beam to form a long scalelength preplasma and by increasing the laser coherence time. In addition, we have studied the role of plasma turbulence, generated by the ISI process, by measuring the growth of SBS from a non-ISI laser produced plasma simultaneously irradiated with an ISI beam.

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Simultaneous spatially and spectrally resolved measurement of $3\omega_o/2$ emission from a laser-produced plasma

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Abstract

Three-halves harmonic emission from a laser-produced plasma has been simultaneously spatially and spectrally resolved. The measurements were made for a 100-ps, 1.06 μm laser pulse incident on a thick molybdenum target and show that the blue-shifted $3\omega_o/2$ peak originated closer to the target surface than the red-shifted peak. This result is consistent with three-halves emission originating from two-plasmon decay (TPD) plasmons propagating up and down the plasma density gradient. The data also shows significant spectral modulation of both the blue and red-shifted peaks which suggests that scattering from ion waves is occuring in the three-halves emission process. Scattering of the three-halves photons from ion waves would explain the presence of the blue-shifted peak in 90 degree side-scatter and the spatial extent of the red-shifted feature to densities below the limit given by Landau damping of the TPD plasmons.

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