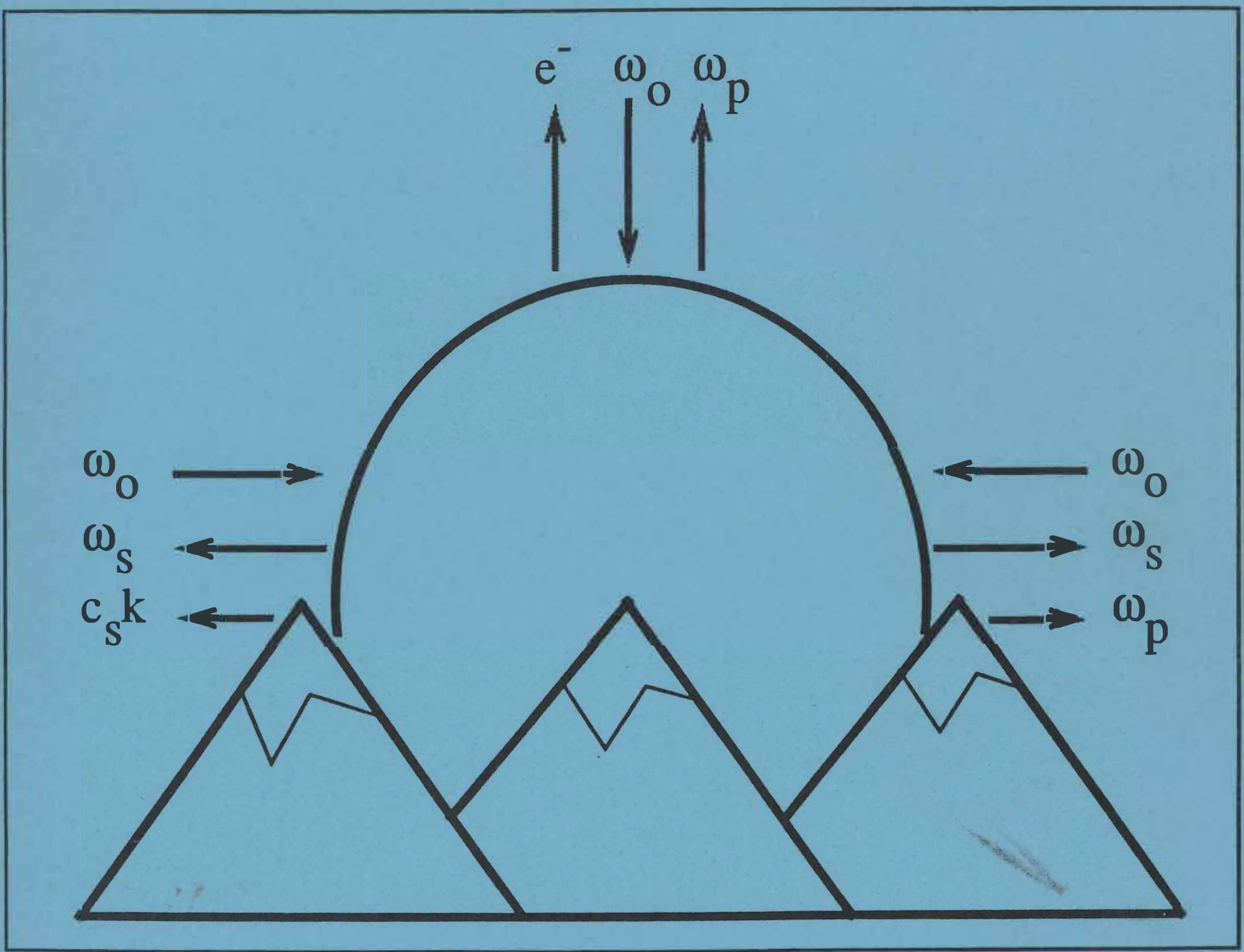
19th Annual Anomalous Absorption Conference

Fort Lewis College, Durango, Colorado



Los Alamos National Laboratory

June 19-23, 1989

19th ANOMALOUS ABSORPTION CONFERENCE

JUNE 19-23, 1989

FORT LEWIS COLLEGE

DURANGO, COLORADO

COORDINATOR - ROGER JONES

PROGRAM

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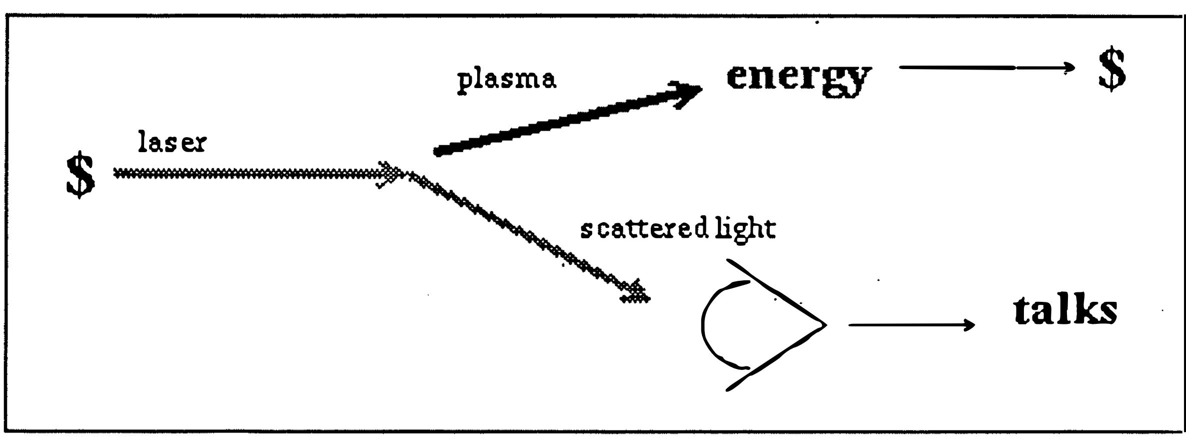

AATITLE

Los Alamos

19th Annual Anomalous Absorption Conference
June 19 - 23, 1989
Durango, Colorado

Monday Morning, 8:30 AM, June 19 - R. Berger, Chair

Invited Talk (30 minutes)

AI Competition between SRS and SBS;
D M Villeneuve, H A Baldis, and J E Bernard

A **Oral Session — Stimulated Raman Scattering (15 Minutes Each)**

A1 Stimulated Raman scattering in the caustic illumination sheath surrounding a laser fusion target;
R W Short

A2 Numerical studies of x-ray emission by fast electron pulses;
A Simon

A3 Backward and forward Raman scattering in long preformed plasmas;
F Amiranoff, C Labaune, C Rousseaux, G Matthieussent

A4 Studies of collapse in two-fluid plasmas;
J P Sheerin

A5 Absolute SRS from density cavities;
H C Barr, T J M Boyd, and A P Mackwood

A6 Simultaneous experimental investigation of the stimulated Raman scattering and the two plasmon decay instabilities;
J Meyer and Y Zhu

A7 Collisional and Landau damping can compete to produce narrow Raman scattered spectra;
R P Drake, E A Williams, P E Young, Kent Estabrook, W L Kruer, H A Baldis, and T W Johnson

A8 Two color experiments using the Nova laser;
P E Young, H A Baldis, D S Montgomery, B A Remington, and K G Estabrook

A9 Investigation of (3/2) ω_o emission and Two Plasmon Decay waves in an underdense CO_2 - laser irradiated plasma;
J Meyer and Y Zhu

Monday Afternoon, 4:00 PM, June 19 – S. Coggeshall, Chair

Special Review Talk (45 minutes)

SR Review of the Current Status of Cold Fusion *J Rafelski*

Monday Evening, 7:30 PM, June 19 – J. Delettrez, Chair

Review Talk (45 minutes)

BR Electron dynamics during laser plasma interaction;
J P Matte

B **Mixed Poster Session**

B1 The relativistic modulational instability of light waves in rarefied plasma;
C J McKinstrie

B2 Excitation of strong Langmuir turbulence in plasmas near critical density: application to HF heating of the ionosphere;
D F DuBois, H A Rose, and D Russell

B3 Effect of optical smoothing on laser-matter interaction;
P A Holstein, J L Bocher, D Desenne, D Galmiche, and F Mucchielli

B4 The role of Induced Spatial Incoherence on stimulated Raman scattering;
P N Guzdar, Y Tan, Y C Lee, C S Liu, and R Lehmberg

B5 Effects of Induced Spatial Incoherence on x-ray conversion;
R A Bosch, E F Gabl, J D Simpson, B H Failor, J M Stiegman, J L Thornburg, and G G Ganger

B6 X-ray emission from laser produced plasmas: effect of pulse shape and duration;
I Toubhans, R Fabbro, J C Gauthier, M Chaker, and H Pepin

B7 Stochastic behavior of resonant absorption in the microwave range;
B Cros, J Godiot, G Matthieussent, and A Héron

B8 Bistability and chaos in beat wave - plasma interaction;
W P Leemans, C Joshi, and C E Clayton

B9 A self-consistent wave-kinetic formulation of wave-plasma interactions;
E R Tracy, A H Boozer and A J Neil

B10 Absolute SRS from a rippled density ramp;
H C Barr, T J M Boyd, and A P Mackwood

B11 Nonlinear coupling of scattering instabilities in laser plasmas;
T Kolber and W Rozmus

B12 1-D non linear SRS/SBS behaviour with Langmuir and sound wave coupling (in homogeneous plasma);
G Bonnaud, D Pesme, and R Pellat

B13 Electron plasma wave breaking and caviton formation;
B S Bauer, L. Scurry, and A Y Wong

B14 Spectroscopic diagnosis of high density laser imploded capsules;
C J Keane, L J Suter, R W Lee, R E Turner, J D Kilkenny, P M Bell, and R S Thoe

B15 Implosion experiments at 0.26 μm;
E Fabre, M Koenig, A Michard, and P Fews

B16 XUV and soft x-ray spectra from picosecond laser-excited plasmas;
D G Stearns, O L Landen, B J MacGowan and C Keane

B17 Laser-produced plasmas in medicine;
S J Gitomer and R D Jones

Tuesday Morning, 8:30 AM, June 20 – D. Matthews, Chair

Invited Talk (30 minutes)

CI Recent ICF Progress at Osaka;
H Takabe, Y Kato, K Mima, and S Nakai

C **Oral Session — X-Rays, X-Ray Lasers and Hydrodynamics-I (15 Minutes Each)**

C1 K-Shell photoabsorption edge spectroscopy in a dense plasma;
A Ng, L DaSilva, B K Godwal, G Chiu, F Cottet, M C Richardson, P A Jaanimagi, and Y T Lee

C2 Recent soft x-ray laser studies at NRL;
E A McLean, T N Lee, J A Stamper, H R Griem, and C K Manka

C3 Observation of gain in Na Hα transition with short laser pulse irradiation;
Y Kato, H Azuma, K Yamakawa, H Takabe, T Tachi, T Nishio, S A Ramsden, and S J Rose

C4 The development of a multi-pass x-ray lasing amplifier;
G Charatis, D J Drake, P D Morley, and J L Trebes

C5 Coherence of x-ray lasers;
R A London, M D Rosen, and Moshe Strauss

C6 X-Ray laser emission from long line-focus plasmas;
R S Craxton

C7 Three dimensional simulations of laser driven implosions;
R P J Town and A R Bell

C8 The ablative Rayleigh-Taylor instability in three dimensions;
J P Dahlburg, J H. Gardner, and Gary Doolen

C9 Effect of radiation transport on Rayleigh-Taylor instability growth rate;
J H Gardner, J P Dahlburg, C R DeVore, and S E Bodner

Tuesday Evening, June 20, 7:30 PM - E Williams, Chair

Review Talk (45 minutes)

DR Key physics issues associated with free electron lasers;
Cha-Mei Tang

D **Mixed Poster Session**

D1 Smoothing and stability of a plasma corona produced by a non-uniform laser irradiation;
J R Sanmartín, J Sanz, J A Nicolás, F Ibáñez, M Pérez-Saborid, and A Barrero

D2 Comparison of enhanced Thomson scattering from long and short scale-length plasmas;
S H Batha, D D Meyerhofer, and A Simon

D3 Collisionally enhanced degenerate four wave mixing in a plasma;
Y Kitagawa, R L Savage, Jr., C Joshi, and C Clayton

D4 Absolute and convective instabilities in infinite homogeneous media;
C J McKinstrie

D5 SRS convective thresholds in a linear density ramp;
H C Barr, T J M Boyd, and Osama Yasein

D6 Pulse-shaping of direct drive capsules for absorbed energies of 100 - 500 kJ;
M Cray, S V Coggeshall, G R Magelssen, and W C Mead

D7 Analysis of recent Nova symmetry and implosion physics experiments;
L J Suter, R E Turner, C J Keane, J D Kilkenny

D8 3D multimode, ablative Rayleigh-Taylor simulation;
J P Dahlburg, J H Gardner, and Gary Doolen

D9 Hydrodynamics of ISI laser light self-focusing;
R Rankin, C E Capjack, and C R James

D10 Measurements of x-ray conversion efficiencies for shaped laser pulse irradiation of gold disks;
C Darrow, H Kornblum, F Ze, J D Kilkenny, and R P Drake

D11 "Photon accelerator": new method of frequency upshifting ultrashort laser pulses;
S C Wilks, J M Dawson, T Katsouleas, and W B Mori

D12 Fast compression of magnetic flux using an imploding cylinder driven by laser beams;
W Choe

D13 Radiative yields from femtosecond targets;
M D Rosen

D14 Interaction experiments with 10 psec pulses;
J E Bernard, D M Villeneuve, and H A Baldis

D15 Creation of high density plasmas using x-ray sources;
L DaSilva, R Falcone, D Matthews, and J Trebes

D16 Gain and line broadening measurements of Lithium-like ions;
J C Moreno, H R Griem, S Goldsmith, and J Knauer

D17 Characterization of a line focus plasma by high resolution x-ray spectroscopy in the keV range;
J C Kieffer, M Chaker, M Hebert, H Pepin, D M Villeneuve, J E Bernard, and H A Baldis

Wednesday Morning, 8:30 AM, June 21 – P Goldstone, Chair

Invited Talk (30 minutes)

EI Planar foil instability and mix experiments at the Helen and Nova lasers;
P Fieldhouse, K Oades, P A Rosen, J C V Hansom, T J Goldsack, N Cowperthwaite, D L Youngs, N Mawhinney, A J Baxter, B R Thomas, J D Kilkenny, D Bach, R Wallace, V Rupert, and P Skokowski

E Oral Session — Hydrodynamics and Ultra-short Interactions-II (15 Minutes Each)

E1 Recent NRL measurements of velocity uniformity and hydrodynamic instability in ablatively accelerated foils;
J Grun, J Stamper, E McLean, S Bodner, K Kearney, C Manka, A Mostovych, S Obenschain, C Pawley, J Dahlburg, M Emery, and J Gardner

E2 Hydrodynamic turbulence due to laser-accelerated foil targets;
J Stamper, J Grun, J Crawford, C Manka, A Mostovych, B Ripin, and E McLean

E3 Second order analysis of Rayleigh-Taylor instability with multi-mode initial condition;
S W Haan

E4 Characterization of plasmas produced by intense, 1-ps, laser pulses;
Y -H Chuang, S H Batha, H Chen, D D Meyerhofer, M C Richardson, and S Uchida

E5 Collisional absorption of short pulses;
R Cauble, F J Rogers, and W Rozmus

E6 Calculation of inverse bremsstrahlung absorption of high-intensity laser light in short scale length plasmas;
D D Meyerhofer, Y -H Chuang, J Delettrez, and M C Richardson

E7 Exact solution of the Boltzmann equation in the presence of an intense laser field;
S Rashid

E8 Equilibrium ionization of high-density matter;
S Pfalzner

E9 Hydrodynamic simulations of ultrashort laser pulse interaction;
J Delettrez, D D Meyerhofer, and M C Richardson

E10 Recombination lasing in plasmas produced by above threshold ionization with ultrashort optical pulses;
G D Enright, N H Burnett, and P B Corkum

Wednesday Evening, 6:00 PM, June 21

Banquet

Business Meeting - R D Jones, Chair

Review Talk (45 minutes) - B Bezzerides, Chair

FR Nonlinear science: from paradigms to practicalities;
D K Campbell,

Thursday Morning, 8:30 AM, June 22 – J Stamper, Chair

Invited Talk (30 Minutes)

GI Caviton nucleation in laser-produced plasmas and the ionsphere;
H A Rose, B Bezzerides, D F DuBois, and D Russell

G **Oral Session — Beam Smoothing and Filamentation (15 Minutes Each)**

G1 Absorption in high-Z targets illuminated with 527 nm laser light at high intensity using Induced Spatial Incoherence;
J D Simpson, E F Gabl, R A Bosch, B H Failor, J M Stiegman, J L Thornburg, and G G Ganger

G2 Improvements to energy and power balance on Omega;
R L Keck, W D Seka, S Letzring, S Morse, and J M Soures

G3 Energy, power balance, and irradiation uniformity on Omega;
W Seka, R L Keck, S Letzring, S Morse, and J M Soures

G4 Anticipated improvement in laser beam uniformity using distributed phase plates with quasi-random patterns;
R Epstein and S Skupsky

G5 Improved laser-beam uniformity using the angular dispersion of frequency-modulated light;
S Skupsky, R W Short, T Kessler, R S Craxton, S Letzring, and J M Soures

G6 A nonlinear theory of the modulational instability;
W Rozmus, and P P Goldstein

G7 The filamentation of two counterpropagating waves;
G G Luther, C J McKinstrie, and R W Short

G8 Power quantization and flux-limited filaments in the static limit;
H A Rose, D F DuBois, and D Russell

G9 Filamentation and refraction;
E A Williams

G10 Enhanced laser penetration and self-focusing in large scale underdense plasmas;
E M Epperlein

Thursday Evening, 7:30 PM, June 22 – S Craxton, Chair

Review Discussion

HR A discussion of the issue of intensity structure in laser beams;
W L Kruer

H **Mixed Poster Session**

H1 A study of the effects of numerical damping on SATIN simulations of stimulated Raman scattering;
L V Powers

H2 1-D non linear SRS/SBS behaviour with Langmuir and sound wave coupling (in inhomogeneous plasma);
G Bonnaud, D Pesme, and R Pellat

H3 Backward and forward Raman scattering in long preformed plasmas;
F Amiranoff, C Labaune, C Rousseaux, and G Matthieussent

H4 Further experimental study of filamentation in laser-produced plasmas;
P E Young, H A Baldis, E M Campbell, K G Estabrook

H5 Investigation of flicker via a simple analytical model;
S V Coggeshall, R D Jones, and W C Mead

H6 "Shine-through:" early-time phenomena in laser fusion targets;
T Boehly, D Bradley, and J Delettrez

H7 Effects of jetting instabilities on ablation of high-Z disks: the role of radiation cooling instability;
W B Fechner and N D Delamater

H8 Plasma blowoff from low-Z/high-Z composite disks;
D Ress and L Suter

H9 Modeling and physical study of confined laser-matter interaction;
J Virmont, D Devaux, R Fabbro, and J Fournier

H10 Beam-plasma instabilities in a dense helium plasma focus;
F Begay and I Lindemuth

H11 2-D simulations of frequency upshifting of EM radiation using a suddenly created plasma;
S C Wilks, J M Dawson, C Joshi, W B Mori, and A Banos

H12 Relativistic wave particle interaction;
R Williams, C E Clayton, C Joshi, T Katsouleas, and W B Mori

H13 The generation of tunable radiation using a relativistic ionization front;
W B Mori

H14 Ionization balance studies in 20 ps laser-produced aluminum plasmas;
R L Shepherd, D Matthews, C Keane, D Elder, J Kennedy, T Phillips, A Osterheld, R Stewart, G Charatis, G Busch, B Bosch, and E Gabl

H15 Picosecond laser generation of harmonics and fluorescence in noble gases;
C C Gomez and R M Sinclair

H16 Frequency shifts of picosecond laser pulses in high density plasmas;
O L Landen, D G Stearns, and E M Campbell

H17 Laser matter interaction with a 1 ps laser pulse;
J C Kieffer, P Audebert, M Chaker, J P Matte, H Pépin, P Maine, D Strichland, P Bado, and G Mourou

H18 Effect of spin on the electron-ion scattering and heating rate of a plasma in a very intense laser field;
S Rashid

Friday Morning, 8:30 AM, June 23 – R Epstein, Chair

Invited Talk (30 minutes)

II Recent progress of beam-plasma interaction experiments with heavy ion beams;
D H H Hoffmann

I Oral Sessions — Heavy Ions, Beat Waves and Miscellaneous (15 Minutes Each)

I1 Study of preheat by time resolved XUV imaging of laser illuminated thin foils;
R Benattar and V Malka

I2 Singular value decomposition applied to a plasma diagnostic;
J F McGrath

I3 1-D and 2-D Fokker-Planck simulations of early-time energy deposition and transport in laser-plasma experiments;
G J Rickard, I. R G Williams, and A R Bell

I4 Effect of laser beam hotspots on parametrc instabilities in non-uniform plasmas;
R L Berger

I5 Ion acoustic decay instabilities in laser-produced plasma;
K Mizuno, P E Young, W Seka, R Bahr, J S DeGroot, R P Drake, and K G Estabrook

I6 Observations on the plasma wave excited by the laser beat-wave;
A E Dangor, A K L Dymoke-Bradshaw, A E Dyson, P Gibbon, and S J Karttunen

I7 Modulational instability in the IC/RAL beat-wave experiment;
A R Bell

I8 Focussing on light waves in beat wave accelerators;
P Gibbon

I9 Test particle dynamics in beat wave excited plasma waves;
P Gibbon

Invited Talk (30 minutes)

Competition between SRS and SBS

D M Villeneuve, H A Baldis and J E Bernard

National Research Council of Canada
Ottawa Canada

Even in idealized theoretical models of SRS, there is a gap between theory and experiment. Unfortunately in the real world there are factors which add another level of complexity to the problem. For example a number of laboratories have reported an interaction between otherwise distinct instabilities.

In an experiment at NRC, a strong competition between SRS and SBS was observed. By intentionally seeding SBS ion waves, it was possible to totally eliminate the SRS.

In thin foil experiments at Livermore, SBS and SRS appeared to be anticorrelated in the Raman gap.

A considerable amount of theoretical work has been done in an effort to understand the interaction between these instabilities, at LANL, UCLA, Wales, Limeil, Alberta and KMS. Some of these models give remarkably good agreement with experimental observations.

ORAL SESSION A
R. Berger, Chair

Stimulated Raman Scattering

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STIMULATED RAMAN SCATTERING IN THE CAUSTIC ILLUMINATION SHEATH SURROUNDING A LASER FUSION TARGET

R. W. Short

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

Abstract

When a spherical laser fusion target corona is illuminated by a laser beam, the turning points of the light rays form a caustic surface around the target, extending from critical density into the underdense corona. Near this surface the light intensity (and hence the ponderomotive potential) has a local maximum, due to the Airy swelling of the electromagnetic wave near its turning point, and so the density has a local minimum. The caustic surface is nearly perpendicular to the density gradient over much of its area, so that the effective density scale length along the surface is large. The surface is also approximately perpendicular to the plasma flow velocity, which is nearly sonic relative to the surface, enhancing the density minimum due to the ponderomotive potential. Thus we have a sheath surrounding the target in which the light intensity is high, with a long effective scale length for waves propagating parallel to the surface, and which contains a local density minimum which can trap plasma waves and light waves near their turning point. It may thus act much like a self-focused filament in terms of its potential for enhancing stimulated Raman Scattering (SRS). The size and depth of the density trough and the light intensity therein will be estimated, and the likely effect on SRS discussed.

"This work was supported by the U.S. Department of Energy Division Of Inertial Fusion under agreements No. DE-FC03-85DP40200 and by the Sponsors of the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics."

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NUMERICAL STUDIES OF X-RAY EMISSION BY FAST ELECTRON PULSES

A. Simon

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

Abstract

A characteristic signature of the presence of fast electrons in a plasma is the emission of hard x-rays. Spectral analysis of the continuum x rays can be used to infer the velocity distribution and number of fast electrons[1], assuming the electrons have an isotropic distribution of velocities and suffer classical slowing down. When the velocities are not isotropic, procedures such as those in Ref. 1 fail, and one must turn to more detailed analysis. We have constructed a computer program to do this, starting from the Weinstock[2] integration of the Sommerfeld[3] dipole matrix elements for a single electron collision with an atom.

Rice and Chamberlain,[4] have reported use of such a program to interpret x ray data obtained during lower-hybrid RF heating of the Alcator-C tokamak. They found that a non-isotropic electron distribution, such as would be predicted by quasi-linear diffusion in a limited and directed velocity range, fit their data better.

We apply our program to study the consequences of various fast electron pulse models of Raman scattering[5]. Some results will be shown.

1. K.A. Brueckner, Nuclear Fusion, 17, 1257 (1977).
2. R. Weinstock, Phys. Rev,. 61, 584 (1942).
3. A. Sommerfeld, Ann. d. Physik, 11, 257 (1931).
4. J.E. Rice and K.L. Chamberlain, Phys. Rev. A, 38, 1461 (1988).
5. A. Simon and R.W. Short, Phys. Rev. Lett., 53, 1912 (1984); A. Simon, W. Seka, L.M. Goldman, and R.W. Short, Phys. of Fluids, 29, 1704 (1986).

"This work was supported by the U.S. Department of Energy Division Of Inertial Fusion under agreements No. DE-FC03-85DP40200 and by the Sponsors of the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics."

19th Anomalous Absorption Conference, Durango, Colorado 1989

Backward and Forward Raman Scattering in long preformed plasmas

F. Amiranoff, C. Labaune, C. Rousseaux, G. Matthieussent*

L.U.L.I Ecole Polytechnique 91128 Palaiseau Cedex France
*Laboratoire P.G.P. Université Paris XI 91405 Orsay Cedex France
Equipes associées au Centre National de la Recherche Scientifique

The scattering of high intensity laser beam in long and homogeneous underdense plasmas through Brillouin and Raman processes can be a problem for future thermonuclear targets. It can lead to the reflection of laser light and to the production of high energy electrons.

A long uniform underdense plasma is created by irradiation of a thin plastic foil (λ = O,53 µm, τ = 500 ps, I = 10^{13} W/cm^2), the first laser beam is focused along a 2 mm long line. The main laser beam (λ = 0,53 µm, τ = 500 ps, I ~ 10^{15} W/cm^2), with an adjustable delay interacts along this preformed plasma. We present time resolved spectra of Brillouin backscattering, forward and backward Raman scattering. Diode signals are analysed to give a measurement of the amount of scattering for each process. This amount of scattering is compared to the one obtained on imploded foils.

A4

STUDIES OF COLLAPSE IN TWO-FLUID PLASMAS

J. P. Sheerin
KMS Fusion, Inc.
Ann Arbor, MI 48106-1567

We have described Langmuir collapse at moderate to high amplitudes using full two-fluid theory.[1,2] Simulations demonstrate the onset of the modulational instability and the formation of solitons at small amplitudes ($W=|E|^2/4\pi nT << 1$) in one dimension. In two dimensions, solitons are subject to collapse, followed by burn-out and nucleation events. For moderate amplitudes, the range of wavenumbers over which these dynamics occur is relatively small (called a "narrow inertial range"). Large-amplitude nonlinear ion waves accompany collapse. For high intensities ($W >> 1$), nonlinear, aperiodic waves grow rapidly to the point of wavebreaking.

1. J. P. Sheerin, D. R. Nicholson, and G. L. Payne, B.A.P.S. **31**, 1446(1986).
2. J. P. Sheerin, M-M. Shen, D. R. Nicholson, and G. L. Payne, (to be published).

ABSOLUTE SRS FROM DENSITY CAVITIES

H.C.Barr, T.J.M.Boyd, and A.P.Mackwood

University of Wales, UCNW, Bangor, Wales, UK

Drake et.al. recently[1] presented evidence that SRS is an absolute instability and in a reply[2] to a comment by Tarvin and Berger[3] suggested that a monotonic density profile upon which sits a localised density maximum/cavity might explain their data. Absolute SRS in a linear density ramp and from a density maximum have been discussed elsewhere[4]. When significant trapping of the plasma waves in a density cavity occurs SRS is qualitatively different from scattering from a density maximum (both are described by the same WKB model when the cavity is shallow). Ignoring damping total trapping of plasma wave energy reduces thresholds to zero. At densities of, say, $0.1n_c$ plasma waves participating in forward scattering from a density minimum require a cavity only a few per cent of $0.1n_c$ to be totally trapped (a backscattering plasma wave requires a much deeper cavity). Such totally trapped plasma waves would result in forward scattering becoming *absolutely* unstable and having *low* (if not zero) thresholds since they are weakly damped. If cavities exist then forward scattering may have the lower thresholds (although more weakly driven).

In the scenario mentioned by Drake et.al.[2], the situation is more complex: it is a combination of the feedback loops which exist for the linear density ramp, the density maximum and the density cavity. We shall present results for cavities as well as for this more complex profile.

[1]R.P.Drake, et.al., Phys.Rev.Lett.60,1018(1988)

[2]R.P.Drake, et.al., Phys.Rev.Lett.61,2387(1988)

[3]J.A.Tarvin and R.L.Berger, Phys.Rev.Lett.61(1988)

[4]H.C.Barr, T.J.M.Boyd, and G.A.Coutts, Phys.Rev.Lett.60,1950(1988);
H.C.Barr, T.J.M.Boyd, and A.P.Mackwood, Phys.Fluids B (to be published)

Simultaneous Experimental Investigation of the Stimulated Raman Scattering and the Two Plasmon Decay Instabilities*

J. Meyer and Y. Zhu
University of British Columbia

We have carried out an experimental study of both the absolute stiumulated Raman scattering (SRS) and the two plasmon decay (TPD) instabilities in a CO_2-laser irradiated plasma using Thomson scattering of probe ruby laser light. In these experiments unstable electron plasma waves (epw) are probed in k_x $(//k_0)$ - k_y $(//E_{co_2})$ - space along a line extending from $(k_o,0)$ to $(3k_o,2k_o)$, Spatial evolution in the density gradient as well as wave vector and frequency spectra of the epw's are measured. According to conventional theory one would expect for our conditions to observe epw's arising from SRS around $(k_o,0)$ and at $k_x > 2k_o$, $k_y > k_o$ where TPD is above threshold, with the two regions separated by a gap. In contrast we observe simultaneous excitation of plasma waves extending continuously from the SRS to the TPD region. We interpret our results based on the speculation that SRS and TPD are just branches of the same instability indicating that at least for certain k-space regions a more complete theory is needed for the calculation of correct thresholds and growth rates.

* Supported by the Natural Sciences and Engineering Research Council, Canada

Collisional and Landau damping can compete to produce narrow Raman scattered spectra

R. P. Drake, E. A. Williams, P. E. Young, Kent Estabrook, and W. L. Kruer
Lawrence Livermore National Laboratory
P.O. Box 808 M/S L-473
Livermore, California 94550

H. A. Baldis
National Research Council
Ottawa, Canada K1AOR6

T. W. Johnston
LINRS-Energie, Varennes
Quebec, Canada JOL2PO

ABSTRACT

Stimulated Raman Scattering (SRS) is a three-wave, parametric instability with important potential adverse effects on laser fusion. One topic of current research is the structure of the spectrum of the scattered light. We will show that narrow Raman spectra can be produced when the collisional damping rate becomes comparable to the homogeneous growth rate for SRS. Landau damping limits the SRS spectrum at long wavelength, and collisional damping and absorption can limit the spectrum at long wavelength, through the variation of the damping rate with plasma density. Data will be shown to demonstrate this effect, from experiments in which constant-intensity pulses of 0.35 μm laser light irradiated 3 μm thick CH targets at intensities < 2 x 1014 W/cm2. The observed spectra have a peak wavelength, spectral width, spectral shape, and time dependence that are consistent with the anticipated effects of damping. In addition, the emission from the plasma is measured to be near thermal levels at heavily damped frequencies.

* 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.

Two color experiments using the Nova laser

P. E. Young, H. A. Baldis[a], D. S. Monthomery, B. A.Remington,,
K. G. Estabrook
Lawrence Livermore National Laboratory, USA

Abstract

We will present results of a recent experiment using the Nova laser in which a green laser beam ($\lambda_o = 0.53\ \mu$m) interacts with a plasma pre-formed using a shorter wavelength beam ($\lambda_o = 0.35\ \mu$m). The uv beam irradiates a thin CH foil which burns through prior to the end of the laser pulse. The green beam is delayed in time relative to the uv beam and interacts with a plasma in which the peak plasma density remains above $n_c/4$ and below n_c for times long compared to the temporal resolution of the diagnostics. We have simultaneously temporally and spectrally resolved SBS, SRS and $3\omega_o/2$ emission from the plasma and find that there is a correlation between the disappearance of $n_c/4$ (when the $3\omega_o/2$ signal drops in intensity) and when the SBS signal drops in intensity. The density decay inferred from the SRS spectrum is consistent with our understanding of the plasma evolution.

*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.

[a]) *National Research Council of Canada, Ottawa, Ontario, Canada*

Investigation of (3/2) ω_o Emission and Two Plasmon Decay Waves in an Underdense CO_2 - Laser Irradiated Plasma.*

J. Meyer and Y. Zhu
University of British Columbia

The angular and spectral distribution of $(3/2)\omega_o$ light emitted from a CO_2-laser irradiated underdense plasma has been measured. The results are interpreted with help of Thomson scattering measurements of two plasmon decay plasma wave k-spectra and theoretical predictions based on the process in which pump photons are scattered off two plasmon decay plasmons. If pump, $(3/2)\omega_o$ photon, and decay plasmon satisfy their wave vector matching condition, then the spectra provide a good temperature diagnostics. Spectra of light scattered off plasmons having propagated up or down the density gradient are severely broadened.

* Supported by the Natural Sciences and Engineering Research Council, Canada

SPECIAL REVIEW TALK SR
S. Coggeshall, Chair

Cold Fusion
J. Rafelski, Speaker

Special Review Talk

Review of the Current Status of Cold Fusion

J. Rafelski
Department of Physics, University of Arizona, Tucson

The two months of intensive activity following the announcement of cold fusion has resulted in a proliferation of ideas and experiments designed to explain and verify the phenomenon. Following the first major workshop devoted to Cold Fusion, held in Santa Fe, New Mexico on May 23-25, the situation remains confused, although it is possible to draw a few preliminary conclusions. Firstly, the observation of neutrons originally announced by Jones *et al* has been confirmed by experiments performed at Texas A&M, Los Alamos and Grand Sasso. These experiments also appear to support the observation of neutron 'bursts' reported some time before from Frascati. However, there are also a number experiments reporting negative results, and until a consensus has been reached we cannot safely judge the presence of neutrons to be entirely secure. The lecture will in particular emphasize the experimental and theoretical developments which have occurred in this now rather well established direction of cold fusion. With regard to the observation of heat reported by Fleischmann and Pons, it was shown that the radiation measurements they performed are incorrect and therefore void. However, since two other very careful heat experiments at Stanford and Texas A&M universities seem to confirm the excess heat. In particular, the Stanford group lead by Huggins now claims to have reached the point where the amount of heat output exceeds that of the *entire* power input, so that recombination of gases cannot be the source of an erroneous observation of heat. The Texas A&M experiments reported by Appleby have been performed using microcalorimetry in which power levels of up to 1 μW can be measured, very much smaller than levels observed. In addition, it was reported that when Lithium was replaced by Sodium in the electrolyte, the heat output vanished. This intriguing observation is now being tested with isotopically pure Lithium. As for experiments looking for reaction products, a significant level of tritium was reported from the Texas A&M neutron experiment, at levels far greater than the observed number of neutrons but far less than that required for the production of observable levels of heat. No significant levels of ^{3}He or ^{4}He have been found. This leaves the theoretical explanation of the cold fusion phenomenon more confused than ever, and it may well be that there are many different cold fusion mechanisms in operation, each with a different signature and sensitivity to the conditions under which the experiment is performed.

REVIEW TALK BR
J. Delettrez, Chair

Electron Transport
J. P. Matte, Speaker

MIXED POSTER SESSION B

19th Annual Anomalous Absorption Conference
Durango, Colorado
19-23 June 1989

THE RELATIVISTIC MODULATIONAL INSTABILITY OF LIGHT WAVES IN RAREFIED PLASMA

C.J. McKinstrie

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

Abstract

The relativistic modulational instability of copropagating light waves is studied. In a rarefied plasma there are additional contributions to the nonlinear current which always suppress the one-wave instability.[1,2] Depending on the laser beat-frequency, the two-wave instability[3] can either exist with a reduced growth rate or be completely suppressed. For two light waves in a beat-wave accelerator the instability does exist, with detrimental consequences for high-energy particle acceleration

1. A.L. Berkhoer and V.E. Zakharov, *Sov. Phys. JETP* **31**, 486 (1970).
2. C.E. Max. J. Arons and A.B. Langdon, *Phys. Rev. Lett.* **33**, 209 (1974).
3. C.J. McKinstrie and R. Bingham, *Phys. Fluids B* **1**, 230 (1989).

"This work was supported by the U.S. Department of Energy Division Of Inertial Fusion under agreements No. DE-FC03-85DP40200 and by the Sponsors of the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics."

EXCITATION OF STRONG LANGMUIR TURBULENCE IN PLASMAS NEAR CRITICAL DENSITY: APPLICATION TO HF HEATING OF THE IONOSPHERE

By

D. F. DuBois, Harvey A. Rose and David Russell
Los Alamos National Laboratory
Los Alamos, NM 87545

ABSTRACT

Results are presented of an extensive study of strong Langmuir turbulence (SLT) in plasmas excited near the critical density by intense coherent radiation beams. The nominal parameters for HF heating experiments imply that the ionospheric plasma is in such a state. A large body of experimental data exists, particularly from incoherent scatter radar (ISR) measurements of HF enhanced fluctuation levels. Long time simulations of Zakharov's model of SLT and related theoretical arguments have led to new conclusions and insights : 1.) Linear parametric instabilities may play a role only during the first few ms after heater turn-on in a quiescent ionosphere, but there is also the possibility of "direct nucleation" of cavitons in preexisting density fluctuations. 2.) The instabilities lead to Langmuir collapse. 3.) The turbulence is sustained by nucleation of trapped electric fields in burnt-out density cavities from previous collapses. 4.) The nucleation-collapse-burnout scenario explains several features of the observed ISR plasma line power spectra in early-time, low duty cycle experiments and predicts new features. 5.) ISR spectra obtained at early times in low-duty cycle heating experiments are consistent with the spectra of correlated caviton events. 6.) These spectra contain a "free mode" peak which is due to the radiation of free Langmuir waves by collapsing cavitons; this peak has recently been observed. 7.) Sharp spectral peaks observed in strong spectra in longer time, high duty cycle or CW heating must arise in the SLT model from spatio-temporal caviton correlations; strong temporal correlations have recently been observed in single radar pulse plasma line power time series. 8.) Correlation models can explain all the sharp features including the decay line, the cascade, the narrow OTSI line and the anti-Stokes line; these models do not involve parametric instabilities. 9.) The turbulent spectrum is much more isotropic relative to the geomagnetic field than weak turbulence predictions. 10.) The altitude dependence of the plasma line is consistent with observation without postulating large-scale density modifications. 11.) The nonlinear absorption rate of heater energy is much larger than collisional absorption, the absorbed energy going mainly into suprathermal electrons. 12.) Caviton correlations are greatly enhanced in overdense domains where the local plasma frequency exceeds the heater frequency.

Effect of optical smoothing on laser-matter interaction

P.A.HOLSTEIN, J.L.BOCHER, D.DESENNE, D.GALMICHE, F.MUCCHIELLI.

C.E.A LIMEIL
94195 Villeneuve St Georges Cedex FRANCE

The uniformity of the laser energy deposition is a key point for the laser-matter interaction. We have tried to assess the effects of two different methods used to smooth the laser non-uniformities with respect to the standard laser irradiation: the smoothing by Random Phase Plate (RPP) and the smoothing with a optical fiber oscillator (OFO) /1/.

Let us recall the basic principle of the last method which has been studied in Limeil: at the output of a broad band oscillator the beam is focused on a 50m-long fiber optics; each beamlet has a different angle with respect to the fiber axis, so the optical path is different and each beamlet is delayed by more than the coherence time of the laser. At the fiber output the beam propagates through a serie of classical amplifiers up to 80mm in diameter.

Two diagnostics have been used to estimate the smoothing:

-the ablation depth on gold measured by X-ray spectroscopy on bilayer foil Al/Au.

-the X-ray conversion efficiency measured by a multichannel device.

The measurements have been done at 1.06µm and 0.53µm. At 1.06um the irradiance is in the range 10^{13}-3.10^{13}W/cm2; the ablation depth is unchanged with the OFO or with a RPP with respect to the standard laser beam. This measurement seems to be in disagreement with our FCI 1D code simulation. On the other hand the X-ray conversion is lightly improved by using the OFO. For 0.53µm laser the experiment is now in progress .

/1/ D.VERON,... Optics com. 65 (1988) p42

B4

The Role of Induced Spatial Incoherence on Stimulated Raman Scattering*

P. N. Guzdar, W. Tan, Y. C. Lee, and C. S. Liu
University of Maryland
Laboratory for Plasma Research
College Park, MD 20742

R. Lehmberg
U.S. Naval Research Laboratory
Washington, DC 20375

In an earlier study[1] we had used a model for the pump laser light, that displayed the effects of I.S.I., to study Stimulated Raman Scattering. We continue these investigations over a wider range of parameters. The three parameters in our problem are γ_0 the homogeneous growth rate (related to the intensity), the bandwidth $\Delta\omega$ and the time delay t_d between the echelons. A systematic dependence of the instability growth on these parameters will be presented.

(1) The Effect of I.S.I. on Stimulated Raman Scattering, by P. N. Guzdar, W. Tan, Y. C. Lee, C. S. Liu and R. Lehmberg, presented at the 18th Annual Anomalous Absorption Conference, L'Estérel, Quebec, June 27-July 1, 1988.

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Poster
Requested

Effects of Induced Spatial Incoherence on Xray Conversion

R.A. Bosch, E.F. Gabl, J.D. Simpson, B.H. Failor, J.M. Stiegman, J.L. Thornburg, G.G. Ganger

KMS Fusion, Inc.
P.O. Box 1567
Ann Arbor, MI 48106

Laser pulses with induced spatial incoherence (ISI) were produced by passing wideband (10 Angstrom) pulses through a 10x10 transmission echelon. Similar pulses without ISI were produced by passing narrowband (0.1 Angstrom) pulses through the echelon. Laser spots of 120 μm diameter and peak intensities of ~5×10^{14} W/cm^2 at λ=.526μm were obtained. Absorption of the incident laser light by 170 μm gold disk targets was increased by 5-10% with ISI. Soft xray conversion (E<800eV) was measured with 170 μm gold disk targets and "burn-through" targets consisting of a 0.5 μm aluminum layer on silicon. For both types of target, the difference in soft xray conversion efficiency resulting from ISI was smaller than the data scatter and experimental uncertainty of ~10%.

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

X-ray emission from laser produced plasmas: effect of pulse shape and duration

I. Toubhans, R. Fabbro
Laboratoire pour l'Utilisation des Lasers Intenses
Ecole Polytechnique, 91128, Palaiseau, Cédex (France)
J.C. Gauthier,
Laboratoire de Physique des Milieux ionisés
Ecole Polytechnique, 91128, Palaiseau, Cédex (France)
M. Chaker, H. Pépin
Institut National de la Recherche Scientifique - Energie
P.O. Box 1020, Varennes, Québec (Canada)

The use of laser-produced plasmas as extremely bright sources of soft X-ray radiation in research and industry applications has been demonstrated in the past few years. These plasmas can provide useful X-ray radiation from 0.1 keV to 5 keV with very small ($\simeq$ 100 μm) source size. Sub-keV emission is potentially relevant to X-ray microscopy and biological analysis in the "water-window". KeV emission is more appropriate for X-ray microlithography.

In this paper, we have studied both experimentally and theoretically the different factors affecting the X-ray spectra in order to optimize them for a given application. The following aspects have been investigated: laser wavelength and intensity, pulse duration, influence of the pulse shape and of the focal spot diameter. An X-ray multichannel and a transmission grating spectrometer have been used in the experiments. The theoretical study has been made using a simple hydrogenic - modified Saha equilibrium - model for X-ray emission (XSOURCE) and more complex hydrodynamic calculations with a code incorporating photon transport physics (X-RAD). The experimental and theoretical results clearly show the range of laser parameters which optimize the conversion efficiency in a given spectral region.

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Stochastic Behavior of Resonant Absorption in the microwave range

B. Cros, J. Godiot, G. Matthieussent, A. Héron

Laboratoire P.G.P. Université Paris XI 91405 Orsay France
Centre de Physique Théorique Ecole Polytechnique 91128 Palaiseau France
Equipes associées au Centre National de la Recherche Scientifique

Resonant absorption of an electromagnetic wave (f = 3.5 GHz) in a multipolar discharge ($n_e \simeq 10^{11} cm^{-3}$) with an adjustable density gradient exhibits a stochastic behavior when the pump field or the gradient length is increased.

Experimental results are compared to those of a 1D numerical simulation of the Zakharov equations. Though the parameters of the simulation are not strictly equal to those of the experiment, an agreement is obtained between results concerning the transition from the usual linear regime towards stochasticity: value of the nonlinear parameter for which it appears, amplitude of the density perturbation.

Bistability and Chaos in Beat Wave - Plasma Interaction

W.P. Leemans, C. Joshi, and C. E. Clayton ,UCLA

The equation of motion for a relativistic Lagrangian electron fluid element in the presence of an ion ripple is being studied analytically and numerically. When the plasma density is varied in time, it is observed that the relativistic mass increase of the plasma electrons gives rise to bistability and hysteresis around $\Delta\omega = 2\omega_p$ and $\Delta\omega=\omega_p$, but no period doubling . The ion ripple however changes the restoring force acting upon the electron fluid element . Depending on the ripple size, this results in an additionally incomplete period doubling cascade or a universal period doubling route to chaos.
This work is supported by the Department of Energy under contract no. DE-AS03-83-ER40120 and Grant no. DE-FG03-87-ER13752.

Abstract for the 19th Anomalous Absorption Conference
Durango, CO June 19-23, 1989

A Self-consistent Wave-Kinetic Formulation of Wave-Plasma Interactions

E. R. Tracy, A. H. Boozer and A. J. Neil
Physics Department
College of William and Mary
Williamsburg, VA 23185

It is well known [1,2] that the ray equations of geometric optics are Hamiltonian in form with the dispersion relation, $\omega = \Omega(x,t,k)$, playing the role of the Hamiltonian and (x,k) the roles of conjugate position and momentum variables:

$$\frac{dx}{dt} = \frac{\partial\Omega}{\partial k} \qquad \frac{dk}{dt} = -\frac{\partial\Omega}{\partial x} \qquad \frac{d\Omega}{dt} = \frac{\partial\Omega}{\partial t}\,.$$

(Here d/dt signifies the total derivative following the ray trajectory.) A wave packet moves like a classical particle in an external potential given by Ω. Because of this special property it is possible to formulate the wave propagation problem (in cases where the assumptions of geometric optics are valid) as a kinetic theory for a gas of quasiparticles [3].

By deriving the relevant equations of motion from an action principle it is possible to self-consistently couple waves to the plasma. This leads to a straightforward derivation of ponderomotive effects from a knowlege of the linear response characteristics of the medium [4].

Here we present an action principle which emphasizes the particle-like nature of ray propagation. This leads directly to a kinetic equation for the waves and a modified fluid equation for the plasma [5]. As a concrete example we then study the ponderomotive filamentation instability of an intense laser beam in a plasma.

Further generalizations and a discussion of numerical applications will also be presented.

1] I. B. Bernstein, Phys. Fluids, 18(1975)320.
2] S. McDonald, Phys. Rep., 158(1988)337.
3] A. Bers, in *Plasma Physics*, ed. by C. DeWitt and J. Peyraud, (Gordon and Breach Science Publishers, New York, 1975), 113.
4] Allan N. Kaufman, Phys. Rev. A, 36, (1987)982.
5] E. R. Tracy and A. H. Boozer, submitted to Physics Letters.

ABSOLUTE SRS FROM A RIPPLED DENSITY RAMP

H. C. Barr, T. J. M. Boyd, and A. P. Mackwood

University of Wales, UCNW, Bangor, Wales, UK

A variety of density structures have been suggested to explain the discrepancy between SRS-C theory and observations which typically see backscattering thresholds an order of magnitude lower than this theory predicts. One such is a density ramp which has been modulated by, for example, ion waves generated by stimulated Brillouin scattering.

We show that such a rippled profile can both aid and deter absolute SRS. If absolute SRS is already possible due to an existing feedback loop, then the modulation can interfere with the fine phase relationships necessary to sustain it, thereby inhibiting the temporal growth. On the other hand, if absolute growth is not already sustainable, the ripple can provide the necessary feedback (mainly plasma wave reflections by the density ripples) to permit temporal growth.

For example, we have solved the full-wave Raman equations for a linear density ramp upon which is superposed a modulation, of wavenumber $2k_0$ and constant local amplitude. The maximum density is chosen to be underdense to forward scattered light. Broadly, in the absence of the ripple, only the lower scattered frequencies can sustain absolute growth. Then the influence of the ripple is to reduce the growth rates and raise thresholds. At the higher scattered frequencies, temporal growth becomes possible only in the presence of a ripple. A realistic profile of ion wave fluctuations, such as has been measured by Baldis et.al[1]., in which strong SBS is observed at the higher densities approaching $n_c/4$ would result in preferential SRS at lower densities. This is without having to invoke ion *dynamics.*

[1] H. A. Baldis, et.al., to be published.

Nonlinear Coupling of Scattering Instabilities in Laser Plasmas

T. Kolber and W. Rozmus

Department of Physics
University of Alberta

A numerical simulation based on a one-dimensional fluid model is used to test the effect of Landau damping and various nonperiodic boundary conditions on stimulated Raman (SRS) and Brillouin (SBS) scattering. The model also contains the nonlinear coupling between ion acoustic and Langmuir waves described by the Zakharov equations. The results from the hydrodynamical model are compared to those obtained from a particle-in-cell simulation in order to elucidate the role of wave particle interaction in the nonlinear evolution of SRS and SBS.

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1-D non linear SRS/SBS behaviour with Langmuir and sound wave coupling (in homogeneous plasma)

G. Bonnaud, D. Pesme†
Commissariat à l'Energie Atomique, Centre d'Etudes de Limeil
94195 Villeneuve st Georges Cedex, France
R. Pellat
Centre de Physique Théorique, Ecole Polytechnique, 91128 Palaiseau Cedex, France

The non-linear behaviour of stimulated Raman scattering (SRS) in an under quarter-critical homogeneous plasma has been numerically investigated; the 1-D numerical code (CHEOPS) is of wave-coupling type and does not make any space/time envelope approximation. As the main result, the ion acoustic wave generated either by the stimulated Brillouin scattering (SBS) or by the Decay instability of the SRS-driven electron plasma wave (EPW) causes the conversion of the EPW into a large wave-vector Bloch-mode. For experimental conditions corresponding to low values of the drive parameter $I_0\lambda_0^2$ (lower value=10^{14} W $\mu m^2/cm^2$) and to several hundred eV for electron temperature, it is found that the subsequent SRS detuning and Landau damping induces a significant SRS-drop without any onset of the modulational instability and pumped langmuir collapse.

Reference: 1.H.A. Rose, D.F. DuBois, B. Bezzerides, Phys. Rev. Lett. 58, 2547 (1987)
2.G. Bonnaud, State Doctorate Thesis, Paris XI University (1989 march)

† Permanent address: Centre de Physique Théorique, Ecole Polytechnique
91128 Palaiseau Cedex, France

Re: 19th Anomalous Absorption Conference

Electron Plasma Wave Breaking and Caviton Formation*

B.S. Bauer, L. Scurry, A.Y. Wong UCLA Dept. of Physics

Cavitons created under conditions of strong electron plasma wave (EPW) fields are investigated. The cavitons are made in the UCLA Small Caviton Device (SCD), a cylindrical coaxial capacitor-plate plasma experiment. A 200 MHz VHF burst is applied to a central rod in an azimuthally symmetric, but radially nonuniform, unmagnetized plasma. Large amplitude EPW are excited at a resonant shell, where the local plasma frequency matches the incident oscillation frequency. Wave electric fields, measured with a diagnostic low density 10 keV electron beam, grow to 100 times the original pump field. The localized electric fields eject electrons from the resonant region, leaving a net positive space charge, which pushes out ions. This results in ion acoustic shock waves, and a cylindrical shell density depression, or "caviton", whose space-time evolution (density, space potential, and electron temperature) is mapped with a Langmuir probe. Fast electrons and ions produced by the caviton are seen with a gridded energy analyzer, and light produced from neutral atoms excited by the fast electrons is detected with a photomultiplier tube.

The largest plasma response is obtained when the resonance is moved to the top of a broad inverse parabolic profile. Electric field energy densities $W = E^2/4\pi nTe > 5000$ are obtained, along with electrons of kinetic energy > 5000Te. The space potential at the resonant layer jumps by $\Delta\phi > 100Te$.

At these excitation levels, kinetic effects are important, and fluid models, such as the Zakharov equations, no longer adequately describe the phenomena. One dimensional particle-in-cell computer simulations have been run, tailored to reflect the experiment as closely as possible. The experimentally determined SCD density and temperature profiles are used; particles are lost when they hit the boundaries; the plasma is allowed to be non-neutral; an antenna potential is put on the left edge, a grounded wall on the right edge. Realistic mass ratios have been used, with the duration (number of pump cycles) of the simulations comparable to the length of the experiment, and 100,000 to 900,000 particles. Quantities of theoretical interest, such as ambipolar potential and ponderomotive force, are directly calculated, to test the accuracy of the Zakharov equations, and other formulations.

The simulations show the excited EPW become highly nonlinear ($\delta n/n >> 1$), ultimately breaking, and producing many energetic particles. After repeated wave-breaking the electron phase-space becomes a many-layered manifold structure, replete with wave-breaking streamers and electron hole vortices. If the resonant layer is highly localized, the ions can have their velocity changed before they have time to move appreciably, violently rupturing the ion phase-space. The highest pump power run, Wo = 1, yielded peak resonant fields (before breaking) of W · 6500, and electron kinetic energies (after wave-breaking) in excess of 100,000Te.

The extent to which electron plasma wave breaking supplements the more gradual ponderomotive force of the wave in ejecting electrons from the resonant layer is considered.

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Spectroscopic Diagnosis of High Density Laser Imploded Capsules*

C.J. Keane, L.J. Suter, R.W. Lee, R.E. Turner, J.D. Kilkenny,
P.M Bell, and R.S. Thoe

Lawrence Livermore National Laboratory

X-ray spectroscopy has been demonstrated to be a effective method for diagnosing conditions in laser imploded capsules.[1] In this paper, we discuss and summarize spectroscopic methods appropriate for diagnosis of the high density plasmas characteristic of these experiments. The discussion will be broken into two areas: line broadening and atomic kinetics.

Broadening of the beta lines of H-like and He-like Ar has been used as a time resolved diagnostic of fuel density in capsules imploded using the Nova laser. In these experiments, the time resolved Ar K-shell spectra from deuterium filled capsules seeded with a small fraction of Ar was monitored using a flat RAP crystal coupled to an x-ray streak camera. The resulting data clearly shows the Ar linewidths increasing in time as the implosion progresses. The electron density at any point in time is inferred by comparing the measured line profile to those computed by various line shape codes. As part of this work, we have performed comparisons of a number of line broadening codes in order to estimate the reliability of this technique. Among these are several generalized codes[2,3] capable of computing line broadening from more complex emitters such as Li-like and Ne-like ions; spectral diagnostics of this type are of interest for use in future higher density implosion experiments.

We are also investigating the kinetics of H- and He-like Ar in these plasmas. Detailed modelling of the Ar spectra is underway to determine the feasibility of using spectral features such as satellite lines as a diagnostic of fuel conditions. Particular emphasis is being placed on developing high energy spectroscopic diagnostics in order to avoid future anticipated problems with capsule opacity.

1. N.D. Delamater et al. , Phys. Rev. A 31, 2460 (1985), and references therein.
2. L.A. Woltz and C.F. Hooper, Jr., Phys. Rev. A 38, 4766 (1988).
3. Code supplied to LLNL by A. Calisti et al., Universite de Provence, France.

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

abstract for the 19th ANOMALOUS ABSORPTION CONFERENCE

IMPLOSION EXPERIMENTS AT 0.26 μm

E.FABRE°, M.KOENIG°, A.MICHARD°, P.FEWS*

° L.U.L.I. Ecole Polytechnique
91128 Palaiseau Cedex FRANCE
* Bristol University GREAT BRITAIN

Direct drive implosion experiments at 0.26 μm laser wavelength have been conducted on large aspect ratio ($100<R/\Delta R<250$) glass microballons. The six beams of the laser,which can deliver 200 Joules at 4ω on the targets, are tangentialy focused with f:1 optics in order to get reasonably good illumination.The major diagnostics implemented on the chamber(neutron yields by scintillators;α particles yields,fuel temperature and shell $\rho\Delta r$ determination by CR 39 foils;X ray pinhole and streak camera photograph) allows us to study three main topics: the implosion dynamic,the particle yields and the hydrodynamic efficiency.The experimental results show that the implosion dynamic is in good agreement with 1-D simulations and indicate that the compression continues to the late stage of implosion.However the particle yields obtained are much lower than those predicted by the code in spite of a rather good convergence ratio($6 < R_0/R_f < 10$).This phenomenon is probably due to some shell-fuel mixing at the beginning of the implosion.Finally we show that the hydrodynamic efficiencies given either by a thermal or kinetic determination lie between 7% and 15%.

XUV and Soft X-ray Spectra from Picosecond Laser-Excited Plasmas*

D. G. Stearns, O. L. Landen, B. J. MacGowan and C. Keane
Lawrence Livermore National Laboratory
P.O. Box 808 M/S L-473
Livermore, California 94550

Abstract

High resolution XUV and soft x-ray spectra from a picosecond laser plasma irradiated by a second probe picosecond laser pulse are presented. Spectra are recorded for carbon, silicon, and gold targets between 35Å and 1200Å using a grazing incidence spectrometer. The variations in the spectra measured as a function of probe intensity, polarization, and previously-inferred plasma density scale-length[1] provide information on the charge states and temperatures reached by picosecond excitation.

1.) O.L. Landen, D.G. Stearns and E. M. Campbell, "Measurement of the Expansion of Picosecond Laser Plasmas using Resonance Absorption Spectroscopy" submitted to Phys. Rev. Lett.

*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.

LASER-PRODUCED PLASMAS IN MEDICINE*

S.J. Gitomer & R.D. Jones
Los Alamos National Laboratory
Los Alamos NM 87545 USA
and
C. Howsare
Uniform Services University of the Health Sciences
Bethesda MD 20814 USA

The laser has found applications in medicine, beginning with uses in ophthalmology in the 1960's. Today, lasers find medical applications in tissue cutting, blood coagulation, photo-dynamic cancer therapy, arterial plaque removal, dentistry, etc. In this paper, we examine the characteristics of plasmas which are produced in laser medicine. In particular, we consider the examples of plasmas produced in laser-lithotripsy [1] (stone ablation and fragmentation by dye lasers) and in ocular photodisruption (lens membrane destruction by Nd:YAG lasers following cataract surgery). Our interest is in what aspects of these plasmas make them useful to these applications. Experimental data will be presented along with hydrocode simulations of the phenomena. We find that the simulations and experiments are in relatively good agreement with regard to plasma temperature, density, pressure, optical emission and evolution of cavitation bubbles. The results of our ability to model emission and absorption spectra, material removal and acoustic wave propagation will be reported as well.

*Work performed under the auspices of the United States Department of Energy.

[1] S.J. Gitomer, R.D. Jones & C. Howsare, "One Dimensional & Two Dimensional Modeling of Laser Ablation & Fragmentation of Human Calculi," SPIE Conference 1066 on Laser Surgery: Advanced Characterization, Therapeutics, and Systems, Los Angeles, CA 15-18 January 1989.

Invited Talk (30 minutes)

Recent ICF Progress at Osaka

H. Takabe, Y. Kato, K. Mima, and S. Nakai
Institute of Laser Engineering,
Osaka University, Suita Osaka 565, JAPAN

At Osaka, the laser driven implosion experiment is done with the Gekko XII laser system. Main efforts of the experiment are devoted to the direct drive scheme with uniform irradiation of 2ω light and the indirect scheme with two bundled irradiation of 3ω light. We have already achieved the highest neutron yield of 10^{13} at $T_i \simeq 10$keV by the use of gas-filled GMB target (LHART) [1]. The purpose of the present-day experiment is to demonstrate high density by imploding hollow-shell targets and provide the data base for the forthcoming ignition experiment by an up-graded system.

The Gekko XII is a 12-beam system of 10 k Joule at 2ω or 3ω. The direct drive experiment consists of two programs, named "Super uniform" and "Foam cryogenic". The former program demonstrated high density compression by the use of CD-shell targets of 500-700 μmΦ and the thickness of 5-15 μm. The DT-equibalent ρR value of 0.1 g/cm^2 was achieved with improved uniformity by using the Random Phase Plate (RPP) [2]. With the RPP the achieved value of ρR has been improved by at most one-order-of magnitude compared to the case without it. The measured neutron yield is, however, still much lower ($\sim 10^{-3}$) than the value predicted with 1-D code in which the nonlocal electron heat transport is self-consistently treated by solving the Fokker-Planck equation of the bulk electron.

The effort of the second program is devoted mainly to the fabrication of wet foam targets with D_2-liquid and studying basic physics such as interaction, preheating, etc. The implosion experiment was also performed to demonstrate neutron yields of almost the same level as the case for the CD-shell targets.

The Indirect drive implosion is the third program. A senario of the implosion is decomposed into x-ray conversion from 3ω light, x-ray confinement (its spectra) in a cavity, the amount of hard x-ray (M-shell x-ray from Au plasma), ablative implosion of target by soft x-ray and so on. The x-ray confinement in a gold cavity has been studied in the range of $I_L = 10^{12}$ - 10^{15} W/cm^2 at 0.35 μm and the so-called confinement parameter N [3] was evaluated. The burn-through of Al and Au foils attached on a window of Au cavity was measured to study the propagation of radiation heat wave. The x-ray spectra and its time-dependence are compared with the simulation for improving the non-LTE model of atomic state is high Z plasma.

[1] H. Takabe et al. Phys. Fluids 31, 2884 (1988).
[2] Y. Kato et al. Phys. Rev. Lett. 53, 1057 (1984).
[3] R. Sigel et al. Phys. Rev. A 38, 5779 (1988).

ORAL SESSION C
D. Matthews, Chair

X-Rays, X-Ray Lasers, & Hydrodynamics-I

19th ANOMALOUS ABSORPTION CONFERENCE

K-SHELL PHOTOABSORPTION EDGE SPECTROSCOPY IN A DENSE PLASMA

A.Ng, L. DaSilva, B.K. Godwal*, G. Chiu, F. Cottet#
Physics Department, University of British Columbia, Canada

M.C. Richardson, P.A. Jaanimagi
Laboratory for Laser Energetics, University of Rochester, U.S.A.

Y.T. Lee
Lawrence Livermore National Laboratory, University of California, U.S.A.

An overview will be presented on our study of K-shell photoabsorption edge spectroscopy as a probe for dense plasma effects. In the experiment, aluminum plasmas compressed to two-fold solid density were produced by laser-driven shock waves. Temporally resolved measurements of x-ray absorption spectra revealed red-shifts in the aluminum K-edge as the shock pressure was varied during the laser pulse. To understand dense plasma effects on the binding energy of inner-shell electrons, a semi-phenomenological model was developed in which degeneracy and continuum lowering contributions due to free electrons and neighbouring ions were treated as perturbations on the continuum and bound state and evaluated using first-principle solid state methods. Hydrodynamic simulations incorporating this model yielded good qualitative agreement with experimental observations.

* Bhaba Atomic Researach Centre, Bombay, India.
# Universitê de Poitiers, Poitiers Cedex, France.

RECENT SOFT X-RAY LASER STUDIES AT NRL*

E.A. McLean, T.N. Lee, J.A. Stamper, H.R. Griem, and C.K. Manka

Plasma Physics Division
Naval Research Laboratory
Washington, DC 20375-5000

Electron collisional excitation lasing at x-ray wavelengths has been observed in line-focus laser-produced plasmas at several laboratories.[1,2,3] At NRL, we now have observed amplified spontaneous emission from Cu, Zn, Ga, Ge, As, and Se, using both thin film and slab targets.[3] A common problem encountered as one tries to achieve high x-ray lasing intensities, is the refraction of the lasing beam away from the lasant plasma by density gradients present in the line focus plasmas. Interferometry,[4] shadowgraphy, and x-ray refracted-angle measurements have been used to better understand this problem. We will report on interferometric measurements made end-on and side-on to the line focus, including a discussion of the techniques to analyze this data.[5,6] Density distributions could be determined to within 50 microns of the target surface. Small plasma filaments perpendicular to the target surface are also observed in these interferograms and shadowgrams.

A discussion of the Z-dependence of the lasing gain for the J=2-1 and the J=0-1 lines will be given and a summary of the measured wavelengths and gains of the lasing lines will be presented. We have found that for our driver laser intensities ($\lesssim 2 \times 10^{13}$ watts/cm^2), germanium is the most efficient lasing medium.

* This work was supported by SDIO

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2. M.D. Rosen, et al., Phys. Rev. Lett. 54, 106 (1985); D.L. Matthews, et al., Phys. Rev. Lett. 54, 110 (1985).
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Observation of Gain in Na Hα Transition with Short Laser Pulse Irradiation

Y. Kato, H.Azuma, K.Yamakawa, H.Takabe, T.Tachi, and T.Nishio
Institute of Laser Engineering, Osaka University
2-6 Yamada-oka, Suita, Osaka, 565 Japan

S.A.Ramsden
University of Hull, Hull, HU6 7RX, England

S.J.Rose
Rutherford Appleton Laboratory,Chilton OX11 0QX, England

ABSTRACT

Planer NaF Targets were irradiated with line-focused 526nm laser light of 28ps pulse duration and 23J of laser energy. Gain or loss of various transitions were determined by comparing line intensities emitted along and transverse to the x-ray laser axis.

The Na Hα transition at 54.2 A shows definite gain whereas other transitions show strong absorption. Comparison of these results with our previous gain values obtained with longer pulse irradiation at 130 ps will be presented.

C4

The Development of a Multi-Pass X-ray Lasing Amplifier

G. Charatis, D.J. Drake, P.D. Morley, KMS*; J. L. Trebes, LLNL**

*KMS Fusion, Inc.

Ann Arbor, MI 48106

**Lawrence Livermore National Laboratory

Livermore, CA 94550

We have begun experiments at KMS in which x-ray lasing can be demonstrated in a multi-pass multi-layer x-ray mirror cavity configuration. Hydrodynamic and ray trace code calculations indicate that this is possible in a plasma in which amplified spontaneous x-ray emission has been demonstrated. Both calculation and progress in the experiments will be reported.

Coherence of X-Ray Laser

Richard A. London and Mordecai D. Rosen
University of California, Lawrence Livermore National Laboratory
and
Moshe Strauss
University of California at Irvine

Coherence is an important property of many lasers. The application of x-ray lasers to holography requires a high degree of both longitudinal and transverse coherence. Longitudinal coherence is expected to be very good, based on the assumption of doppler broadened line profiles. To date there has been little effort in understanding the transverse coherence properties of x-ray lasers or in designing them for high coherence.

We describe a model for the transverse coherence of exploding foil x-ray lasers, based on a modal analysis of the paraxial electromagnetic wave equation. We assume a steady state, and introduce spontaneous emission with a fluctuating polarization term. Particular transverse electron density (which gives rise to refraction) and gain profiles are assumed. The wave equation is solved by factoring the field into transverse and longitudinal components. An eigenvalue equation is solved for a set of transverse eigenfunctions or modes of the electric field. The longitudinal variation of each mode is characterized by a complex exponential function. Analytic expressions for the radiation intensity and the complex degree of coherence involving sums over the modes are found by taking the appropriate ensemble averages of field products.

Explicit solutions for the transverse eigenfunctions and eigenvalues for the cases of constant and parabolic electron density and gain profile are given. Using the parabolic case as a model, we discuss the expected coherence fraction of the output of exploding foil x-ray lasers, and how this scales with various parameters such as wavelength, gain, electron density, and transverse scalelength. Predictions are given for the results of planned experiments to measure the coherence length by double-slit interferometry

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X-RAY LASER EMISSION FROM LONG LINE-FOCUS PLASMAS

R.S. Craxton

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

Abstract

The code CASER[1] has been used to calculate the x-ray amplified spontaneous emission from line-focus laser-produced plasmas. CASER solves the radiation transport equation along whatever three-dimensional x-ray trajectories are necessary to replicate a variety of experimental observations; it is used as a postprocessor to SAGE, which calculates the two-dimensional hydrodynamics of the line-focus plasma. One important effect, relevant to Livermore experiments using a long line focus ($\leq$ 5 cm)[2] and multipass amplification,[3] is the finite speed of x-ray propagation through the gain medium. For exploding foils, where the density profile changes rapidly with time, the intrinsic gain in the medium can change appreciably during the transit time of an x-ray photon along the line focus. This effect has been included in CASER, and leads to closer agreement between simulation and experimental observations.

1 R.S. Craxton, Bull. Am. Phys. Soc. 33, 2042 (1988).
2 D.L. Mathews et al., J. Opt. Soc. Am. B 4, 575 (1987).
3 N.M. Ceglio et al., Opt. Lett. 13, 108 (1988).

"This work was supported by the U.S. Department of Energy Division Of Inertial Fusion under agreements No. DE-FC03-85DP40200 and by the Sponsors of the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics."

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Three Dimensional Simulations of Laser Driven Implosions.

R P J Town and A R Bell

Plasma Physics Group
The Blackett Laboratory
Imperial College
Prince Consort Road
London
SW7 2BZ
UK

Abstract

Laser fusion targets can be characterised as passing through three phases: acceleration, coasting and deceleration. The stability of the targets is of crucial importance to laser fusion. We have written a three–dimensional fluid code in spherical geometry to model the growth of target perturbations. Results will be presented in the coasting and deceleration phases.

This work has been supported by the UK Science and Engineering Research Council under grant no. 86513266.

The Ablative Rayleigh-Taylor Instability in Three Dimensions

Jill P. Dahlburg, John H. Gardner

LCP&FD, Naval Research Laboratory, Washington, DC

and Gary D. Doolen

CNLS, Los Alamos National Laboratory, Los Alamos, NM

We report the results from a series of fully three-dimensional simulations of the ablative Rayleigh-Taylor instability in cartesian geometry. Flat plastic [CH] targets in hydrodynamic steady state are perturbed with a single mode and are illuminated on one side by a moderate intensity red ($\lambda_L = 1.054\mu$m) or ultraviolet ($\lambda_L = 0.26\mu$m) laser beam. In all simulations, early time, linear RT growth rates from 3D perturbed (k_y, k_z) targets are identical to those obtained from 2D perturbed (k_y) targets, for a given perturbation wavenumber k. However, we find that as the simulations proceed, the subsequent nonlinear evolution of an unconstrained 3D target can be considerably different from that described by a 2D model, in ways that are analogous to other 3D unstable flows.

The nature of the difference can best be studied by considering mechanisms that generate rotational velocities (vorticity) from the interaction of existing vorticity and velocity. These mechanisms, termed vortex tilting and stretching, are indicative of secondary hydrodynamic instabilities in shear flows, circular jets, and other 3D unstable hydrodynamic configurations. It has been conjectured that they precipitate the explosive transition to turbulence at subcritical Reynolds numbers[1]. We here present evidence that vortex tilting and and stretching, with the attendant possibility of turbulent transition, is observed in 3D single-mode ablative Rayleigh-Taylor calculations. This secondary hydrodynamic instability alters the flow pattern near the target, feeding more mass into the RT spike than would be possible in 2D. Subsequently, the 3D Rayleigh-Taylor spikes are wider in cross section and extend further toward the laser than do the 2D spikes. This behavior is particularly apparent in cases for which the ratio k_y/k_z approaches 1. There, the amplitude of nonlinear saturation can be up to 40% larger in 3D than it is for a comparable 2D system.

[1]S. A. Orszag and A. T. Patera *J.Fluid Mech.* **128**, 347 (1983).

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Effect of Radiation Transport on Rayleigh-Taylor Instability Growth Rate

John H. Gardner, Jill P. Dahlburg, and C. Richard DeVore
LCP&FD, Naval Research Laboratory, Washington, DC

Stephen E. Bodner
Plasma Physics Division, Naval Research Laboratory, Washington, DC

We report the results of calculations aimed at elucidating the effects of radiation transport on the growth of the Rayleigh-Taylor instability in laser accelerated thin targets. We compare the results from simulations of flat plastic [CH] targets accelerated with $1/4\mu m$ laser light of mid-10^{14} W/cm^2 laser intensity, with and without radiation transport. It is found that radiation transport increases the mass ablation rate for a given laser intensity and reduces the growth rate of the Rayleigh-Taylor instability even in moderately low Z targets.

For these calculations we use a multigroup, variable Eddington radiation transport model coupled to our FAST2D laser matter interaction code. Laser energy is absorbed by inverse bremsstrahlung. It is transported to the target surface in two stages. Classical thermal conduction transports the energy to a region of higher density where some fraction of the energy is converted to soft X rays. The X rays are then transported further towards the target by the multigroup transport process to a second absorption front dominated by X-ray absorbtion. This results in two distinct fronts; each is subject to Rayleigh-Taylor instability but both have growth rates lower than the classically predicted growth rates. The eigenmode structure is considerably different than that of the classical Rayleigh-Taylor picture.

Recent numerical simulations have shown that in the absence of radiation effects the growth rate for the Rayleigh-Taylor instability in laser absorbing plasmas is reduced below its classical value according to the formula proposed by Takabe et al.[1]

$$\frac{\gamma}{\sqrt{kg}} = 0.9 - 3\sqrt{\frac{k}{g}\frac{\dot{m}}{\rho}}.$$

Thus an increase in mass ablation or decrease in ablation density may be used to alter the Rayleigh-Taylor instability. We investigate the use of various low Z materials to control the density profiles and thus the Rayleigh-Taylor instability.

[1]H. Takabe, L. Montierth, and R. L. Morse, *Phys. Fluids* **26**, 2299 (1983);
H. Takabe, K. Mima, L. Montierth, and R. L. Morse, *ibid.* **28**, 3676 (1985).

Work supported by USDOE and ONR

REVIEW TALK DR
E. Williams, Chair

Free Electron Laser
Cha-Mei Tang, Speaker

Review Talk (45 minutes)

Nineteenth Anomalous Absorption Conference
Durango, CO, 19-23 June 1989

Key Physics Issues Associated with Free Electron Lasers*

CHA-MEI TANG, Naval Research Laboratory, Washington, DC

Free Electron Lasers (FELs) are currently under intense research and development throughout the world for a variety of applications. This talk will review the principle of the FEL and discuss a number of key physics issues which limit the performance of the FELs. These issues include, among others, i) the generation and propagation of high quality, high current electron beams, ii) optical guiding of the generated radiation beam, iii) wiggler noise and iv) the excitation of sideband radiation. Perhaps the most important component of an FEL is a high quality electron beam. For efficient FEL operation the effective electron beam energy spread should be sufficiently small. For reasons which will be discussed, the effective energy spread is determined by i) transverse beam emittance, ii) wiggler transverse spatial gradients, iii) wiggler noise effects, iv) beam space charge effects, v) intrinsic energy spread and vi) energy stability. Another important aspect of FEL operation is optical guiding of the generated radiation beam. In many proposed FEL experiments, the short wavelength radiation beam will not be confined by a waveguide structure and the interaction length will be long compared to the free space Rayleigh (diffraction) length. Optical guiding of the generated radiation, therefore, can play a central role in the practical utilization of FELs. These, as well as other physics issues, will be discussed in detail and theoretical criteria and numerical simulations will be presented.

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MIXED POSTER SESSION D

SMOOTHING AND STABILITY OF A PLASMA CORONA PRODUCED BY A NON-UNIFORM LASER IRRADIATION

J.R. Sanmartín, J. Sanz, J.A. Nicolás and F. Ibáñez.

Escuela Técnica Superior de Ingenieros Aeronáuticos.
Universidad Politécnica de Madrid. 28040 MADRID-SPAIN.

M. Pérez-Saborid and A. Barrero.

Escuela Técnica Superior de Ingenieros Industriales.
Universidad de Sevilla. 41012 SEVILLA-SPAIN.

A linear analysis of the perturbed hydrodynamics due to non-uniform laser illumination of spherical targets is considered. The analysis allows for light refraction through the corona and absorption at the critical surface. Results have been obtained for wavelengths of the illumination disturbances which are either much smaller than the target radius (planar case) or comparable to it (spherical case). Results show that a thermal self-focusing instability may develop in the ablated plasma as a consequence of light refraction. The effect of inverse bremsstrahlung absorption on the obtained results has been considered in some particular cases.

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"COMPARISON OF ENHANCED THOMSON SCATTERING FROM LONG AND SHORT SCALE-LENGTH PLASMAS"

S.H. Batha, D.D. Meyerhofer, and A. Simon

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

Abstract

Frequency up-scattered light produced by laser-plasma interaction was measured under three different plasma conditions. The corresponding down-scattered light was also observed. The measured wavelengths were, in all cases, in good agreement with the results of the enhanced Thomson scatter (ETS) theory. Enhanced Thomson scattering is not a local instability, but rather depends on the action of remote nonlinear plasma processes and instabilities to produce suprathermal electrons that enhance background plasma waves to large amplitudes. Incoming laser light scatters from the enhanced density fluctuations into two "plasma-line" features, one on each side of the laser frequency. The position of these bands depends on the suprathermal electron temperatures through the phase velocity of the plasma waves that are enhanced.

Experiments were performed with the GDL system at LLE and the Nova system at LLNL. The primary variations in the plasmas studied were in scale length, laser wavelength, laser energy, and laser intensity. The scale lengths varied from 80 to 1500 μm. The laser energy varied between 60 J and 20 kJ and the intensity varied between 8 and $48 \times 10^{14}/cm^2$.

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Abstract for the
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Collisionally Enhanced Degenerate Four Wave Mixing in a Plasma

Y. Kitagawa, R. L. Savage, Jr., C. Joshi, and C. Clayton

Electrical Engineering Department
University of California, Los Angeles, CA 90024

We report the first experimental demonstration of phase conjugation via degenerate four wave mixing in a collisional plasma. The experiment was performed with the usual arrangement[1] of the two pump and the probe beams for DFWM. The angle between the probe and forward pump beams was 2.4°. The beams interacted in 10^{17} electrons/cm^3 Ar^+ plasma over a length of approximately 1.5 cm. The grating wavenumbers were $k_{fp} = 248\ cm^{-1}$ and $k_{bp} = 1.18 \times 10^4\ cm^{-1}$. The pump beam intensities were 100 MW/cm^2, whereas the probe beam had an intensity of 10 MW/cm^2. The laser operated on a single longitudinal mode at the 10 P_{20} (10.6 μm) line of the CO_2 laser with a FWHM pulsewidth of ~ 150 ns. The main results[1] of our work are as follows:

a) Most of signal reflectivity was from the small k_{fp} grating as expected in a collisional plasma.
b) The signal reflectivity scaled as electron density, n_e^6 again as predicted by theory.
c) The reflectivity scaled as $I_{probe}^{0.4}$ and $I_{pump}^{0.8}$.
d) The thermal force enhancement of the signal reflectivity was a factor 100 over the ponderomotive force contribution.
e) The third order susceptibility, χ_3, of the plasma ($n_e / n_c \sim 10^{-2}$) at 10 μm wavelength was found to be 1.5×10^{-12} e.s.u.
f) The response time of the small k_{fb} plasma grating was found to be about 50 ns.

The scaling of the signal reflectivity in a collisional plasma can be shown to be

$$R \propto \frac{\lambda^{10} n_e^6 I_f I_b L^2}{T_e^{10}}$$, where L is the interaction length.

Thus, collisional plasmas appear to be extremely promising for phase conjugation via DFWM, particularly in the microwave regime.

[1] Y. Kitagawa, R. L. Savage, Jr., and C. Joshi, Phys. Rev. Lett. 62, 151 (1989).

D4

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ABSOLUTE AND CONVECTIVE INSTABILITIES IN INFINITE HOMOGENEOUS MEDIA

C.J. McKinstrie

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

Abstract

An important distinction between instabilities in infinite homogeneous media is whether they are absolute or convective. Unfortunately, however, the physics inherent in this distinction is often obscured by the mathematical analysis required to determine the time-asymptotic pulse shape. A simple example is presented for which there is an exact analytic solution and which displays many important aspects of instability physics. A curious anomaly in the historical development of the "standard" mathematical technique is also discussed.

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SRS CONVECTIVE THRESHOLDS IN A LINEAR DENSITY RAMP

H.C.Barr, T.J.M.Boyd, and Osama Yasein

University of Wales, UCNW, Bangor, Wales, UK

It has been shown previously[1] that a global analysis of SRS in a linear density ramp permits absolute instability over a wide band of scattered frequencies ω_s and not just at $\omega_s = \omega_0/2$. This is due to feedback between backwards and forwards scattering resonances. The absolute instability thresholds are then typically a factor of four lower than the those predicted by conventional SRS-C theory for backscattering and more than an order of magnitude lower when compared with SRS-C forward scattering thresholds. Below these absolute instability thresholds there exists, in general, a regime of convective amplification. Thus, the convective thresholds (amplification of $e^{2\pi}$) resulting from a global analysis will be more than a factor of four lower than conventional SRS-C theory suggests. We quantify this by solving the full-wave SRS equations appropriate to the convective regime.

[1] P.Koch and E.A.Williams, Phys Fluids, 27, 2346(1984); H.C.Barr, T.J.M.Boyd, and G.A.Coutts, Phys.Rev.Lett. 60, 1950(1988)

D6

PULSE-SHAPING OF DIRECT DRIVE CAPSULES FOR ABSORBED ENERGIES OF 100 - 500 kJ

M. Cray, S.V. Coggeshall, G.R. Magelssen, and W.C. Mead

Los Alamos National Laboratory

ABSTRACT

A number of different direct drive capsules have been designed using 1-D LASNEX simulations for absorbed energies ranging from 100-500 kJ. Capsules with foam and Be ablators have been considered. The results of LASNEX simulations exploring the pulse sensitivity of these targets will be given.

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

Analysis of recent Nova symmetry and implosion physics experiments*

L. J. Suter, R. E. Turner, C. J. Keane, J. D. Kilkenny, LLNL

We will discuss and present data supporting the three major conclusions that resulted from recent Nova implosion experiments which were diagnosed via diagnostic tracer emission. The conclusions are:

1- We have a good, quantitative understanding of symmetry in our current Nova hohlraums.

2- We have a good understanding of the gross hydrodynamics of these capsules. This makes them a good starting point for investigating less tractable physics such as pulse shaped hydrodynamics and mix.

3- The Detailed Configurational Accounting code [1] does an excellent job modelling the atomic physics of the fuel dopant. We can confidently use it in the future to plan and interpret sophisticated, spectrally diagnosed implosion physics experiments.

1-Y. T. Lee, D. S. Bailey, G. B. Zimmerman, Detailed Configuration Accounting Kinetic Code for Non-LTE Plasmas, 1985 Laser Program Annual Report, UCRL-50021-85, p. 2-81.

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

3D Multimode, Ablative Rayleigh-Taylor Simulation

Jill P. Dahlburg, John H. Gardner

LCP&FD, Naval Research Laboratory, Washington, DC

and Gary D. Doolen

CNLS, Los Alamos National Laboratory, Los Alamos, NM

We numerically investigate the 3D evolution of a perturbed 50 μm thick CH target illuminated on the x_+ side with a red ($\lambda_L = 1.054$ μm) laser beam that emanates from $x = +\infty$. The target, assumed to be 120 μm $\times$ 120 μm in y, z cross section, is randomly seeded with wavelength λ_y, λ_z = 30, 40, and 60 μm perturbations. These perturbations are imposed in ten computational zones (2.6 μm) immediately to the x_- side of the target density peak. Each λ_y, λ_z mode constitutes a mass perturbation of O(2×10^{-4}%) or a density perturbation of about 10^{-3}%. The maximum summed density perturbation is 1.4×10^{-2}%.

For the calculation, we used our new laser matter interactions code, *FAST3D*[1]. This code solves the 3D Euler equations for an ideal gas using the flux-corrected transport method. Laser energy is deposited by inverse bremsstrahlung and transported by classical Spitzer thermal conduction. A sliding-zone Eulerian mesh tracks the steep gradients in the RT unstable region while ensuring accurate resolution of developing rotational flows. The gridding for this run is $200 \times 60 \times 60$ (x, y, z) zones, with 0.26 μm zones near the ablation surface and no greater than 0.72 μm zones in the region of the nonlinearly evolving spikes.

The simulation was continued for a total of 14 ns. A y, z Fourier transform of the x-integrated target mass indicates that the perturbed modes grow exponentially (linearly independently) for about 7 ns, until each mode reaches a mass perturbation of a few hundredths of a percent. Subsequently the modes begin to interact, with both larger and smaller scale structures being generated. The modes in the bulk of the target tend to be dominated by small, initially excited wavelengths with $\lambda_y/\lambda_z = 1$, as expected from our previous single mode 3D calculations. Disturbances in the lower density blowoff plasma immediately to the x_+ side of the target turbulently interact. By 14 ns this 3D, stratified turbulence has generated visibly dominant excitation in the largest y, z scales allowed, in the low density ablating plasma.

[1]J. P. Dahlburg and J. H. Gardner *Phys.Rev.Lett.,* (submitted, 1989).

Work supported by USDOE and ONR.

D9

Hydrodynamics of ISI laser light self-focusing

R. Rankin, C.E. Capjack, and C.R. James,

Department of Electrical Engineering,

University of Alberta, Edmonton, Canada T6G 2G7.

Abstract

A two-dimensional cylindrically symmetric Eulerian hydrodynamic plasma simulation code is used to study self-focusing of ISI (induced spatial incoherence) laser light in an inhomogeneous plasma. At high intensities, $I_0 \sim 10^{17} Wcm^{-2}$ (where I_0 represents the intensity which would be achieved for a perfectly coherent beam) thermal self-focusing can occur as a result of small amplitude pressure driven oscillations of the electron density. The dwell time of the filamentary structures varies from being as short as the coherence time of the laser light to a few tens of picoseconds. A similar time dependence is observed at lower incident intensities, $I_0 \sim 10^{16} Wcm^{-2}$, but the level of self-focusing is very significantly reduced.

D10

Measurements of X-ray Conversion Efficiencies For Shaped Laser Pulse Irradiation of Gold Disks*

C. Darrow, H. Kornblum, F. Ze,
J. D. Kilkenny, and R. P. Drake

Lawrence Livermore National Laboratory
Livermore, California. 94550

We have recently performed experiments for the purpose of studying the time-resolved x-ray conversion efficiency of temporally shaped 0.35 μm laser pulses. At present we have developed a technique for reproducibly generating a prescribed laser pulse shape and have used this pulse to irradiate gold disks. The x-rays produced were monitored with a ten-channel (hν ≈ 0.2 - 1.5 keV) time-resolved (to 200 ps) x-ray spectrometer. By varying the laser energy and focal spot size we were able to measure time-resolved x-ray conversion efficiencies and x-ray pulse shapes for several irradiation intensities and for several variations of the nominal prescribed laser pulse shape. These results will be discussed within the context of production and controlled shaping of soft x-ray pulses.

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Abstract for the
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"Photon accelerator": New Method of frequency upshifting ultrashort laser pulses

S.C. Wilks, J.M. Dawson, T. Katsouleas and W.B Mori

Department of Physics
University of California
Los Angeles, CA 90024 USA

A novel method of frequency upshifting short (≤ 1 picosecond) pulses of a laser light, which makes use of relativistic plasma waves, is described. This method makes use of the fact that a laser pulse moving in a plasma can be thought of as a packet of photons, each possessing an effective mass of $m_\gamma = \hbar\omega_{pe}/c^2$ and moving with the group velocity of the laser pulse. These photons experience a force acting on them when in the presence of a gradient in the plasma density. By using a relativistic plasma wave (i.e., a moving density gradient) traveling with the photons, the energy of the photons (thus the frequency) can be continuously increased. Results from 1-D, particle-in-cell simulations of this scheme will be shown, as well as a short discussion on some important 2-D effects.

D12

Fast Compression of Magnetic Flux Using An Imploding Cylinder Driven by Laser Beams

W. Choe
University of Illinois at Urbana-Champaign, Illinois U.S.A.

presented at the 19th Annual Anomalous Absorption Conference
Durango, Colorado, U.S.A.
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A method is proposed for magnetic flux compression inside a cylindrical liner driven by laser beams. A liner considered is a thin cylindrical shell comprised of two layers; an inner layer made of a conducting material and a plastic outer layer. The conducting layer should be as thin as possible to maximize the effects of laser compression, but thick enough to prevent significant loss of the entrapped magnetic field lines. The outer layer is ablated by a set of laser beams which generate a rocket force, driving the liner toward its cylindrical axis. The potential of this scheme as a magnetic pulse generator with a rise time faster than 1 μs, $\dot{B}_{max}$ of 10 T/ns, and peak magnetic field strength greater than 10^3 T is examined using a one-dimensional time-dependent model.

D13

Radiative Yields From Femtosecond Targets*

M. D. Rosen

University of California
Lawrence Livermore National Laboratory
Livermore, California 94550

We have modeled a wide variety of targets that have been or will be illuminated by femtosecond laser pulses at a range of irradiances spanning several orders of magnitude. The basic scaling of plasma temperature is derived, and confirmed by simulations. Designs of experiments to monitor heat transport are presented. Predictions for radiation output in terms of spectra, power, and temporal duration are compared to data and other published predictions.

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

Interaction Experiments with 10 psec Pulses

J E Bernard, D M Villeneuve and H A Baldis

National Research Council of Canada
Ottawa Canada

The LP2 glass laser system at NRC has been modified to amplify 10 psec pulses. The input pulse is generated by a 100 psec pulse chirped and dispersed in a fiber, then compressed by bandwidth narrowing in a YAG regenerative amplifier. The resulting pulse is propagated through the LP2 amplifiers, using aggressive spatial filtering, to produce greater than 10 J on target, corresponding to a peak intensity of 5×10^{16} W/cm^2. Results of some initial plasma characterization, such as x-ray spectra, will be presented.

Creation of high density plasmas using X-Ray sources

L. Da Silva and R. Falcone
University of California at Berkeley

D. Matthews and J. Trebes
*Lawrence Livermore National Laboratory**

ABSTRACT

An extension of optical laser-plasma interaction studies is to utilize high power x-ray sources or x-ray lasers to create high density plasmas. In our work x-rays generated by a laser irradiated gold target are focussed with a nickel plated ellipsoidal mirror onto an isolated target. The mirror intercepts a solid angle of ~ 5×10^{-3} sr and images the source spot with l:l magnification. An aluminized lexan filter was used to prevent stray laser and plasma light from also being focussed on the secondary target. The x-ray spectrum, energy and focal spot distribution on target have been measured and indicate that with a laser energy of 30 J ($\lambda_L = 0.53$ µm, $\tau_L = 1$ ns) we can achieve x-ray flux densities of ~ 3 J/cm^2. Details of these measurements along with some preliminary results on the effects of x-ray heating on multilayered mirrors will be presented.

* 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.

Gain and Line Broadening Measurements of Lithium-like Ions*

J.C. Moreno, H.R. Griem, S. Goldsmith
Laboratory for Plasma Research
University of Maryland
College Park, MD 20742-3511

J. Knauer
Laboratory for Laser Energetics
University of Rochester
Rochester, NY 14623-1299

Spectroscopic measurements were made of lithium-like Al and Mg emission lines from laser-produced plasmas. Flat targets, consisting of thin layers of Al or Mg coated on a Mylar backing, were irradiated with up to 8 beams of the OMEGA laser system employing a line focus configuration. The Al XI 4f-3d line at 154.7 Å exhibited a gain coefficient of 4.1 ± 1.2 cm^{-1} from comparisons of line intensities from 3 mm and 6 mm long plasmas. Similarly the 4d-3p line at 150.7 Å and the 5f-3d line at 105.7 Å had gain coefficients of 4.5 ± 1.3 cm^{-1} and 3.5 ± 0.8 cm^{-1}, respectively. The line width of the Al XI 5f-3d line was measured to be 0.35 Å, while the same transition in Mg X had a line width of 0.48 Å. These lines widths are much larger than the expected Doppler and instrumental width and can be attributed to Stark broadening. Using a simple theory for Stark broadening we obtain an electron density of $\sim 3 \times 10^{19}$ cm^{-3} for both the Al and Mg plasmas.

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

D17

Characterization of a line focus plasma by high resolution X-ray spectroscopy in the keV range

J.C. Kieffer[a], M. Chaker, M. Hébert, H. Pépin,
INRS-Energie, C.P. 1020, Varennes, Québec, JOL 2PO, Canada
D.M. Villeneuve, J.E. Bernard, H.A. Baldis
National Research Council, Ottawa, Ontario, K1A OR6, Canada

We have used the LP2 glass laser of NRC (200 J, 3 ns) to produce Al and Cu line focus plasmas (1 mm to 8 mm long by 100 μm). Two bent crystal spectrometers in Johann geometry are used to do high resolution spectroscopy ($\lambda/\Delta\lambda \simeq 5000$) and X-ray monochromatic images of the plasma in the keV range (7 Å - 13 Å). A pinhole camera and a flat crystal have also been used. We will discuss monochromatic images obtained at various Cu (Neon like) and Al (Resonance and intercombination Helium-like) wavelengths. Preliminary results on the distribution of the plasma parameters obtained from the spectra and the monochromatic images and spatially resolved in one and two dimensions will be discussed.

a) On leave from Univ. P. Sabatier, UA277 du CNRS, Toulouse, France.

Invited Talk (30 minutes)

Planar Foil Instability and Mix Experiments at the HELEN and NOVA Lasers

P Fieldhouse†, K Oades, P A Rosen, J C V Hansom, T J Goldsack, N Cowperthwaite, D L Youngs, N Mawhinney, A J Baxter, B R Thomas

Atomic Weapons Establishment, Aldermaston, Berks, England

J D Kilkenny, D Bach, R Wallace, V Rupert, P Skokowski

Lawrence Livermore Laboratory, CA USA

† *To be presented at the 19th Anomalous Absorption Conference, 19-23 June 1989, Fort Lewis College, Durango, Colorado*

Summary

This paper reviews the current programme of unstable hydro and mix experiments being performed by AWE at the HELEN laser and in collaboration with LLNL at the NOVA laser.

In these experiments planar foil packages are accelerated by radiation from a laser heated driver. Hydrodynamic instabilities - both Richtmyer-Meshkov and Rayleigh-Taylor - leading to turbulent mixing at the interface between the ablator (light 'fluid') and the foil payload (heavy 'fluid') are diagnosed using the technique of point projection X-ray backlighting spectroscopy, in which a near point source of X-rays of short duration, together with a Bragg crystal, provides simultaneous temporal (~ 100 ps), spectral (few eV) and two-dimensional spatial (~ 10 μm) resolution in the film image. Intermixing at the ablator/foil boundary - initial surface finish ~ 0.1 μm rms - is identified in the radiograph from the overlap of characteristic absorption features associated with each of the constituent materials.

Typical plasma conditions in the experimental package - close to the region of mix - at the time of measurement [4-10 ns delay and few 100 μm downstream] are of order $\leq$ few 10's eV and 0.1 to a few g cm^{-3} density; interface velocities of ~ few 10^6-10^7 cm sec^{-1} are obtainable with peak ablation drive pressures of 10-40 Mb.

The paper will review the experimental concept and technique and briefly highlight progress made at the two laboratories in the past two years. The procedures used in processing the experimental radiographs and in unfolding the spatial distribution of mix will be described by reference to one specific 'high mix' shot (#7772) recorded at HELEN for which the data have been fully analysed. The analysis will be discussed, various sources of error [in particular 'edge-effects'] considered and a comparison made with 1-D and 2-D hydrocode simulations; the sensitivity of the predicted mix to the input parameters in the codes (eg spectral drive, preheat, opacity and equation-of-state data) will be underlined.

The talk will conclude by showing a few of the recent results from NOVA and will outline future plans and goals for continued collaboration in this programme.

ORAL SESSION E
P. Goldstone, Chair

Hydrodynamics-II, Short-Pulse Interactions

Recent NRL Measurements of Velocity Uniformity and Hydrodynamic Instability in Ablatively Accelerated Foils.

J. Grun, J. Stamper, E. McLean, S. Bodner, K. Kearney, C. Manka, A. Mostovych, S.Obenschain, C. Pawley Laser Plasma Branch.

J. Dahlburg, M. Emery, J. Gardner, Laboratory for Computational Physics

Naval Research Laboratory, Washington DC 20375

The velocity uniformity and hydrodynamic instability of ablatively accelerated foils are important issues in ICF. Great progress has been made in smoothing laser beams with the introduction of ISI at NRL, RPS at Osaka, and SSD at Rochester. However, there have been few direct measurements of velocity uniformity with these methods. Similarly, RT instability experiments have not been completely explained by theory. Recent hydrodynamic calculations indicate that radiation transport may be needed to understand RT experiments.

NRL has just completed an extensive set (70 data shots) of experiments to address the above issues. In these experiments flat foils were accelerated with a 0.5um laser (4-ns FWHM, mid 10^{12}W/cm^2) to speeds of 100 km/sec. We measured the rear surface temperature, velocity uniformity (with double foils), acceleration history (with x-ray sidelighting), and RT growth (with x-ray backlighting). A new important feature of the experiments is that acceleration, and RT growth, and temperature were measured simultaneously on each shot. We do not rely on codes or shot-reproducibility arguments for one of these items. The velocity uniformity, acceleration history, and impact foil temperature were also measured simultaneously in the uniformity study.

Our measurements addressed these issues:

- Velocity uniformity was measured with a green driver and low irradiance to minimize smoothing by the cloudy-day effect. ISI-smoothed and non-smoothed laser beams were used for comparison.
- RT wavelengths of 25, 33, 50 ,75 ,85, and 100 um were used.
- Target thickness was varied to change acceleration in the RT experiment.
- Perturbation depth was varied from 0.2 to 1um to minimize and detect the onset of nonlinear effects.
- Different target materials were used to see if x-ray preheat makes a difference in RT growth.
- Square and sinusoidal target perturbations were compared to see if RT is effected by presence of multiple modes.

Results will be compared to hydrocodes with and without radiation.

Supported by the U.S. D.O.E.

HYDRODYNAMIC TURBULENCE DUE TO LASER-ACCELERATED FOIL TARGETS*

J. Stamper, J. Grun, J. Crawford+, C. Manka, A. Mostovych, B. Ripin, and E. McLean

Plasma Physics Division
Naval Research Laboratory
Washington, DC 20375-5000

Hydrodynamic turbulence is produced when a laser-irradiated foil target is ablatively accelerated in an ambient gas. Optical probing studies of this turbulence provides a data base whose analysis should be helpful in understanding the complex turbulent structures of astrophysical and atmospheric interest. Typically, 30 to 350 Joules from a PHAROS III laser beam (1 micron) is focused to a diameter of .8 mm onto a 9 or 20 micron thick CH plastic foil target, which is located in a 5 Torr ambient of nitrogen. Turbulence is produced ahead of the ablatively-accelerated dense target material. The turbulent structure is probed with a half-micron, short-pulse (.3 nsec) laser beam. By spatial filtering in the Fourier-transform plane of a collector lens, the structure is recorded either as a dark-field shadowgram or as a phasogram (phase contrast). Unfiltered (bright-field) shadowgrams were simultaneously recorded by using polarization-dependent beam splitting. These diagnostics allow us to quantify the power spectra of the turbulence. Photographs of the structure will be shown and the temporal and spatial variations discussed.

* Supported by the U.S. Defense Nuclear Agency

+ Southwestern Texas State University

Second Order Analysis of Rayleigh-Taylor Instability With Multi-Mode Initial Condition*

Steven W. Haan
Lawrence Livermore National Laboratory
University of California
Livermore, CA 94550

ABSTRACT

The equations describing the Rayleigh-Taylor instability for inviscid, incompressible fluids with surface tension are expanded to second order in the Fourier modes. The resulting differential equations, which include quadratic mode coupling terms, can be solved at intermediate times during which the spectrum is dominated by a group of modes which are themselves not yet strongly affected by the nonlinearities. Coupling between these modes drives up the amplitudes of other modes, both harmonics at higher wavenumbers and other long wavelength modes at smaller wavenumbers. For the long wavelengths we can see explicitly how memory of initial conditions is lost, already at the early stages of nonlinearity. Memory of initial conditions is lost at this time if and only if the long wavelength amplitudes in the marginally nonlinear spectrum go to zero faster than k for small k. Examining the solution in various situations, we see that nonlinearity becomes important when the dominant modes reach amplitude about $1/Lk_p^2$, where L is the system size and k_p the wavenumber at which the amplitude peaks.

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19-23 June 1989

CHARACTERIZATION OF PLASMAS PRODUCED BY INTENSE, 1-ps, LASER PULSES

Y-H. Chuang, S.H. Batha, H. Chen, D.D. Meyerhofer, M.C. Richardson, and S. Uchida

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

Abstract

We present studies of high-intensity laser-plasma interactions using the Tabletop Terawatt(T^3) laser. The laser, based on the principle of chirped-pulse amplification, operates at 1.053 μm wavelength with a pulse duration of 1 ps. It is currently operated in a single-pulse mode with energies up to 100mJ and focused intensities up to ~10^{16} W/cm^2. The laser is also operated at 0.527 μm through frequency doubling.

We have measured the absorption of laser light in plasmas produced during interactions with various materials using an Ulbrecht's sphere. The laser characteristics, including, intensity, polarization and incident angle were systematically changed. Charge collectors and x-ray pin diodes were used to study the characteristics of the ions and electrons. X-ray and XUV spectroscopy were used to measure the spectral emission from the plasmas. Parametric processes were studied using integer and half integer harmonic emission spectroscopy.

"This work was supported by the U.S. Department of Energy Division Of Inertial Fusion under agreements No. DE-FC03-85DP40200 and by the Sponsors of the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics."

Collisional Absorption of Short Pulses*

R. Cauble, F.J. Rogers,
Lawrence Livermore National Laboratory, Livermore, CA
and
W. Rozmus,
University of Alberta, Edmonton, Alberta

The advent of intense, subpicosecond laser pulses has opened a new window in the study of very high density plasmas. When such a pulse is focused on a solid, much of the laser energy absorbed by the ionizing electrons is rapidly conducted away by cold matter below an absorption skin depth. The result is a cool (1 - 500 eV), very dense (10^{24}-10^{25} cm^{-3}) plasma. The theoretical interpretation of these experiments rely on the electron-ion collision frequency, which governs laser light absorption, and on the electron thermal conductivity, which controls plasma cooling. The form of the collision frequency must be appropriate to strongly coupled plasmas in the presence of a strong electromagnetic pump source. We modify a previous calculation[1] for the collision frequency in strongly coupled plasma to include the presence of the strong pump. We approximate the required particle spatial distributions to provide an analytic, but reasonable, result which is referenced to a numerical solution using particle correlation functions in the hypernetted chain approximation. We also comment on the correct form of the electron thermal conductivity in strongly coupled plasma.

[1] R. Cauble and W. Rozmus, Phys. Fluids **28**, 3387 (1985)

* This work was partially performed under the auspices of the U.S. Department of Energy at LLNL under Contract No. W-7405-ENG-48.

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Durango, Colorado
19-23 June 1989

CALCULATION OF INVERSE BREMSSTRAHLUNG ABSORPTION OF HIGH-INTENSITY LASER LIGHT IN SHORT SCALE LENGTH PLASMAS

D.D. Meyerhofer, Y-H. Chuang, J. Delettrez, M.C. Richardson

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

Abstract

Classical calculations of the inverse-Bremsstrahlung absorption coefficient[1] are valid in long scale-length plasmas for low intensity laser irradiation. When the scale length of the plasma is less than the quiver amplitude of the electron in the laser, $x_{osc}=eE/m\omega^2$, or when the quiver velocity, $v_{osc}=eE/m\omega$, is greater than the thermal velocity of the electrons, the assumption of constant collision frequency over the particle orbit is invalid. For example, when $v_{osc}>v_{te}$, the inverse Bremsstrahlung absorption coefficient is reduced by a factor of roughly $(v_{te}/v_{osc})^3$. In addition, when p-polarized light is obliquely incident on a target in a short scale length plasma, the plasma density is nonuniform over the electron orbit.[2] We present calculations of the inverse Bremsstrahlung absorption of high intensity laser light in short scalelength plasmas. These calculations include integration of the particle orbits in the laser field.

1 W.L. Kruer, "The Physics of Laser Plasma Interactions" (Addison-Wesley Publishing, Redwood City, Ca. 1988).
2 F. Brunel , Phys. Rev. Lett. 59 (1987) 52.

"This work was supported by the U.S. Department of Energy Division Of Inertial Fusion under agreements No. DE-FC03-85DP40200 and by the Sponsors of the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics."

EXACT SOLUTION OF THE BOLTZMANN EQUATION IN THE PRESENCE OF AN INTENSE LASER FIELD

SHAHID RASHID
RPO 9888, P.O.Box 5063
New Brunswick,NJ

In the presence of an intense laser field we treat the electrons as quasi- free which means they are solutions to the minimally coupled Dirac equation. With this picture, we exactly solve the Boltzmann equation by the separation of variables method. The solution is a product of the initial distribution function and a time evolving part. We apply the result to the case of a Maxwellian electron gas in a quasineutral plasma. We use the approximation for a cold plasma so that the mean electron kinetic energy is very small compared to the energy of the photons absorbed, I.e. $2mlh\nu >> p^2$. For intensity of he laser field when the Kibble parameter, $\epsilon_k = \frac{E_q}{mc^2}$, where E_q is the quiver energy of the electron in the laser field, is much smaller than one, the solution is obtained as a Maxwellian distribution where the temperature is a time dependent quantity given by

$$T(t) = T(1 - \alpha_r t).$$

α_r is directly proportional to the intensity of the laser field.

The second case we consider is the hot plasma case. The cross section calculated under the Born approximation from our previous paper (Phys. Rev. A **38**, 2525 (1989)) is used. We obtain a nonmaxwellian distribution which is given by

$$f(v,t) = n\left(\frac{A}{2\pi}\right)^{3/2} /(1 - 2Ab(t)/\pi^{1/2})\, exp(-Av^2 - B(t)/v).$$

oral talk

Equilibrium Ionization of High-density Matter

S. Pfalzner, Inst.f.Angewandte Phsik, Hochschulstr.4a,
6100 Darmstadt, Germany

Ultrashort laser pulses as well as intense heavy ion beams are capable of producing high-Z plasmas of electron densities not accessible before in the laboratory. Depending on the parameter $\Gamma = (Z^*e)^2/R_o kT$ three density domains can be distinguished in the plasma. In the case of classical plasmas, $\Gamma \ll 1$, the Maxwell-Boltzmann distribution is valid and the ionization degree can be described by the Saha equation. If $\Gamma \gg 1$ the electron gas is fully degenerated and ionization occurs by the pressure the surrounding ions exert on the single atom. In this region it is shown that the Thomas-Fermi(TF) equation for cold matter can be used for calculating the ionization degree. The different extensions, namely Thomas-Fermi-Dirac(TFD), TFD with electron correlations, gradient corrections etc. are evaluated and it is shown that the improvements due to TFD are essential.

In the transition region $\Gamma \simeq 1$ the electron gas is partially degenerate. So the influence of the temperature has to be taken into account which means that Fermi-Dirac statistics has to be used. The temperature-dependent TF model and its corrections are taken to calculate the ionization degree of dense plasmas. It is shown that from the TFD extension results a far better description for low ionization degrees than from the simple TF model.

In the case of dense and high-density matter outer shells of neighbouring atoms overlap and, as a consequence, the ionization potentials of atoms and ions are reduced. By using the temperature-independent TF model we are able to calculate the ionization potentials with increasing density.

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"Hydrodynamic Simulations of Ultrashort Laser Pulse Interaction"

J. Delettrez, D.D. Meyerhofer, and M.C. Richardson

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

Abstract

We present the results of full hydrodynamic simulations of ultrashort laser pulse interaction experiments. The simulations are carried out with the 1-D code LILAC in which the absorption of the laser light at short scale lengths is calculated by solving the one-dimensional wave equation.[1] The electrical conductivities were obtained from either a Drude model, fit to experiment,[2] or from the SESAME tables. We concentrate this study on the results of experiments carried out on the T^3 laser at Rochester by the group at INRS[3] and on more recent experiments on T^3. We compare the measured absorption to the calculated value for the laser intensity range 10^{13} to 5×10^{15} W/cm^2 and s- and p-polarization at several angles. The dependence of the scale length, and of the resulting absorption fraction, on the laser conditions (intensity, pulse width, prepulse, and polarization) is discussed. Simulations of other published experiments are also considered. Finally, we use code results to discuss the prospects of directly heating high density plasma with ultrashort laser pulses.

1) J. Delettrez *et al*, Bull. Am. Phys. Soc. **33**, 2060 (1988).
2) H. M. Milchberg *et al*, Phys. Rev Lett. **61**, 2364 (1988).
3) J. C. Kieffer *et al*, Phys. Rev. Lett. **62**, 760 (1989).

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Recombination Lasing in Plasmas Produced by Above Threshold Ionization with Ultrashort Optical Pulses

G.D. ENRIGHT, N.H. BURNETT, and P. B. CORKUM

National Research Council of Canada

Ottawa, Canada

Recent advances in ultrashort pulsed laser technology should allow the production of highly over-ionized low-Z plasmas by means of optical field induced ionization. These plasmas should be of interest for recombination XUV lasers in both transient two level systems and adiabatically cooled three level systems. Gain calculations for hydrogen and lithium-like ions will be presented. Some of the plasma physics issues involved in the production of such suitably dense cold plasmas with sub-picosecond UV laser pulses will be discussed.

BANQUET
(Enjoy!)

BUSINESS MEETING
R. Jones, Chair

BANQUET TALK FR
B. Bezzerides, Chair

Chaos
D. Campbell, Speaker

X200

AASEPFR

FR

Review Talk (45 minutes)

"NONLINEAR SCIENCE: FROM PARADIGMS TO PRACTICALITIES"

David K. Campbell
Director, Center for Nonlinear Studies
Los Alamos National Laboratory
Los Alamos, NM 87545

ABSTRACT

Much of the recent excitement surrounding the interdisciplinary subject of "nonlinear science" arises from the recognition that nonlinear phenomena, although occurring in many apparently different contexts in natural sciences and engineering, often display common features or can be understood using similar concepts. These common concepts or features, usually called paradigms, have provided an effective way of viewing nonlinear problems and of going beyond our standard, linear intuition.

In this colloquium-level presentation, we define and discuss three of the most important nonlinear paradigms: "solitons", "deterministic chaos", and "fractals". We present examples of natural systems in which each of these paradigms occurs, describe briefly the underlying concepts and mathematical structures they reflect, and illustrate them with slides and a short film. We close with a brief description of some of the potential practical applications of nonlinear science.

Invited Talk (30 minutes)

CAVITON NUCLEATION in LASER-PRODUCED PLASMAS and the IONOSPHERE

Harvey A. Rose, B. Bezzerides, D.F. DuBois and D. Russell

Los Alamos National Laboratory Los Alamos, New Mexico 87545

The goals of our research include the development of a theory of strongly driven, high frequency plasma turbulence (commonly called strong "Langmuir Turbulence" - or SLT) and its application to experiments including laser-plasma interactions and experiments involving the modification of the ionosphere with powerful radio waves("HF" heating).

From the standpoint of basic science, the Langmuir turbulent system is a fascinating nonlinear system exhibiting the interplay of chaotic behavior, locally coherent (soliton-like) structures, collapse and long range order. There are certain universal scaling properties of SLT which make it applicable to different physical settings with such diverse scales as laser-produced plasmas, ionospheric heating and type III radiations from the solar wind.

In contrast to previous theories of steady state SLT, we have established that cavitons (a local depletion in the plasma density in which a high frequency field is trapped) are driven up by a quasi resonant nucleation[1] process by the external radiation sources. The nucleation process is controlled by the nature of the low frequency density fluctuations and it is through this mechanism that SBS provides a control over SRS[2]. If the Langmuir ponderomotive force in the caviton dominates other low frequency forces, then the caviton collapses to small dimensions where the localized Langmuir mode energy is converted to hot electrons on a time scale short compared to an ion acoustic time scale. The now empty cavity relaxes until nucleation again becomes efficient.

Besides successfully explaining the observed[3] coupling of SRS and SBS we have also explained much of the large experimental base of HF heating[4,5] using SLT.

[1] G.D. Doolen, D.F. DuBois and H.A. Rose, PRL 54, 804(1985).
D. Russell, D.F. DuBois and H.A. Rose, PRL 56,838(1986).

[2] H.A. Rose, D.F. DuBois and B. Bezzerides, PRL 57,2022(1986).

[3] C.J. Walsh, D.M. Villeneuve and H.A. Baldis, PRL 53,1445 (1984).
D.M. Villeneuve, H.A. Baldis and J.E. Bernard, PRL 59,1585 (1987).

[4] P.Y. Cheung, D.F. DuBois, H.A. Rose, D. Russell, J. Santoru, T. Tanikawa and A.Y. Wong, "Short Time Scale Evidence for SLT During HF-Heating of the ionosphere", submitted to PRL.

[5] D.F. DuBois, H.A. Rose and D. Russell, "Excitation of SLT by HF Heating of the Ionosphere: Cavitons vs. Parametric Instabilities" - in preparation.

ORAL SESSION G
J. Stamper, Chair

Beam Smoothing & Filamentation

ABSORPTION IN HIGH-Z TARGETS ILLUMINATED WITH 527nm LASER LIGHT AT HIGH INTENSITY USING INDUCED SPATIAL INCOHERENCE

J.D. Simpson, E.F. Gabl, R.A. Bosch, B.H. Failor, J.M. Stiegman, J.L. Thornburg, G.G. Ganger

KMS Fusion, Inc., P.O. Box 1567, Ann Arbor, Mi. 48108

ABSTRACT

In order to attain the target illumination uniformity required for high gain laser fusion, an optical technique called Induced Spatial Incoherence (ISI) has been proposed[1] to produce highly uniform laser beam profiles. **Previous studies** using this technique have indicated an increase in x-ray yield and a corresponding decrease in laser backscatter (increased absorption), for **low-z targets at 527nm** and low intensity[2] ($<10^{14}$ **W/cm^2**), and **high-z targets at 1050nm** and moderate intensity[3] (**$1-2x10^{14}$ W/cm^2**). In **our experiments, 527nm absorption** for **ISI** and **non-ISI** illumination of **high-z targets** over the **$0.5-3x10^{14}$ W/cm^2** intensity range, was measured using a custom designed 30cm diameter light integrating sphere. In order to produce ISI and non-ISI data for comparison, we irradiated a large number of 180 um diameter gold disks with 0.5-1.5ns pulses, with echelons in the beam path with and without bandwidth. The incident, scattered, and transmitted energy components were measured using volume absorbing calorimeters outside the target chamber, and photodiodes on the sphere equator. Sphere calibrations were done at regular intervals throughout the campaign to track sphere degradation and insure acurate scattered light measurements. **Results indicate** a clear **systematic increase in absorption of 5-10%** over the range of observed incident intensities, and are consistent with results reported earlier for low-z and long wavelength studies[2,3]. Moreover, the data suggest that there is a weaker dependence of absorption on intensity, over this intensity range, for ISI illuminated targets than for non-ISI. The presentation will include target shot and calibration data, as well as some discussion of integrating sphere performance and accuracy.

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

****

1./R.H Lehmberg and S.P. Obenschain, Opt. Commun. **46**, 27 (1983)

2./S.P. Obenschain et. al., Phys. Rev. Lett. 56, 2807 (1986)

3./D.R. Kania, P. Bell, and S.P. Obenschain, SPIE **913**, 98 (1988)

G2

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Durango, Colorado
19–23 June 1989

"IMPROVEMENTS TO ENERGY AND POWER BALANCE ON OMEGA"

R. L. Keck, W. D. Seka, S. Letzring, S. Morse, J. M. Soures

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

Abstract

The on target energy and power balance of the OMEGA laser has recently been improved by incorporating changes to crystal tuning, beam energy balancing, and transport optics measurement. These changes include: improved control of the input polarization to the frequency conversion crystals, a computer assisted crystal tuning procedure and automated temperature compensation system, beam energy balancing using a computer automated closed loop energy distribution system, and laser to target transport optics transmission measurements using a chopper stabilized ratiometer system. In addition, a technique for quantitative evaluation of on-target energy balance using x-ray pinhole photographs has been implemented.

"This work was supported by the U.S. Department of Energy Division Of Inertial Fusion under agreements No. DE-FC03-85DP40200 and by the Sponsors of the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics."

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Durango, Colorado
19-23 June 1989

"Energy, Power Balance, and Irradiation Uniformity on OMEGA"

W. Seka, R.L. Keck, S. Letzring, S. Morse, and J.M. Soures
LABORATORY FOR LASER ENERGETICS
University of Rochester
250 East River Road
Rochester, NY 14623

Abstract

We discuss the important contributing factors to energy and power balance and the on-target irradiation uniformity on OMEGA. An intensity nonuniformity on target of 1 to 2 percent rms implies not only a commensurate energy balance in the UV but also power balance in the UV, i.e. equal UV pulse shapes in all 24 beams as well as equal on-target foot prints of all beams. These conditions can only be met if the laser is operated very close to IR energy balance with minimal pulse shape distortion in the amplifier chain followed by very nearly perfect frequency tripling in all beams. An analysis of OMEGA's past performance identified a number of problem areas most of which have since been corrected. Power balance is typically most difficult to ascertain at early times during the pulse if imperfect frequency conversion or other nonlinear effects are compensated for by adjusting the IR input energy to the crystals. Under the best conditions, we estimate from simulated pulse shape analysis that the present power balance on OMEGA ranges below 5 to 6% rms over the entire pulse.

"This work was supported by the U.S. Department of Energy Division Of Inertial Fusion under agreements No. DE-FC03-85DP40200 and by the Sponsors of the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics."

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Durango, Colorado
June 19 - 23, 1989

ANTICIPATED IMPROVEMENT IN LASER BEAM UNIFORMITY USING DISTRIBUTED PHASE PLATES WITH QUASI-RANDOM PATTERNS

R. Epstein and S. Skupsky

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

Abstract

The uniformity in focused laser beams, that has been modified with distributed phase plates (DPP's), can be improved further by constructing patterns of phase elements which minimize phase correlations over small separations. The size and wavelength of the nonuniformity is determined largely by correlations between phase-plate elements. Long-wavelength nonuniformities in the intensity distribution, which are are relatively difficult to overcome at the ablation surface by thermal smoothing and in the laser by, e.g., spectral dispersion (SSD), result from short-length correlations in the DPP pattern. We have constructed phase patterns with smaller short-range correlations than would occur randomly. Calculations show that the long-wavelength nonuniformities in single-beam intensity patterns can be reduced with these masks. We will show how the degree of improvement depends on the intrinsic phase error of the beam. In the quasi-random patterns considered, low values of the phase correlation are obtained, regardless of which portion of the DPP is included in the average. As a result, the phase plates are tolerant to an appreciable level of phase nonuniformity in the laser output. We will also show the effect of this improvement on the uniformity of spherical illumination by multi-beam systems.

"This work was supported by the U.S. Department of Energy Division Of Inertial Fusion under agreements No. DE-FC03-85DP40200 and by the Sponsors of the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics."

19th Annual Anomalous Absorption Conference
Durango, Colorado
19-23 June 1989

IMPROVED LASER-BEAM UNIFORMITY USING THE ANGULAR DISPERSION OF FREQUENCY-MODULATED LIGHT

S. Skupsky, R.W. Short, T. Kessler, R.S. Craxton, S. Letzring, and J.M. Soures

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

Abstract

A new technique is presented for obtaining highly smooth focused laser beams. This approach is consistent with the constraints on frequency tripling the light, and it will not produce any significant high-intensity spikes within the laser chain, making the technique attractive for the high-power glass lasers used in current fusion experiments. Smoothing is obtained by first imposing a frequency-modulated bandwidth on the laser beam using an electro-optic crystal. A pair of gratings is used to disperse the frequencies across the beam, without distorting the temporal pulse shape. The beam is broken up into beamlets, using a phase plate, such that the beamlet diffraction-limited focal spot is the size of the target. The time-averaged interference between beamlets is greatly reduced because of the frequency differences, and the results is a relatively smooth diffraction-limited intensity pattern on target.

"This work was supported by the U.S. Department of Energy Division Of Inertial Fusion under agreements No. DE-FC03-85DP40200 and by the Sponsors of the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics."

A NONLINEAR THEORY OF THE MODULATIONAL INSTABILITY

W. Rozmus
Department of Physics, The University of Alberta

P.P. Goldstein
Institute for Nuclear Studies, Warsaw, Poland

A nonlinear theory of the modulational instability is analyzed by means of the nonlinear Schrödinger equation (NLS). The Rayleigh-Ritz variational method is applied to solve NLS equation; the spacially periodic trial function is constructed from the combination of Jacobian elliptic functions. The initial conditions correspond to the slightly modulated plane Langmuir wave. A system of ordinary differential equations which results from the principle of least action is derived to provide a basis for numerical and analytical calculations.

The analytical criteria for the nonlinear steepening of the wave envelope and the periodic in time pulsation of the solution are derived. The results of the variational approach compare well with the results of direct integration of the NLS equation.

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THE FILAMENTATION OF TWO COUNTERPROPAGATING WAVES

G.G. Luther, C.J. McKinstrie, and R.W. Short

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

Abstract

The filamentation instability of counterpropagating light waves is studied within the framework of two coupled nonlinear Schroedinger equations; one equation for each complex wave amplitude. Using standard methods of linear stability analysis, one can show that an absolute instability can arise for two waves whose individual intensities are both below the single-wave filamentation threshold. In addition, the coupled-wave system can be absolutely unstable even when the ratio of the backward-wave amplitude to the forward-wave amplitude is small. Such an instability may occur in the context of inertial confinement fusion when scattered light, or light reflected from the critical density surface, interacts with the incident light. While the Schroedinger-equation model is sufficiently general to apply to a host of relevant problems, only the preliminary results of this analysis for the ponderomotive filamentation of laser light will be presented.

"This work was supported by the U.S. Department of Energy Division Of Inertial Fusion under agreements No. DE-FC03-85DP40200 and by the Sponsors of the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics."

POWER QUANTIZATION AND FLUX-LIMITED FILAMENTS IN THE STATIC LIMIT

Harvey A. Rose, D.F. DuBois and D. Russell

Los Alamos National Laboratory Los Alamos, New Mexico 87545

Most static models[1] of filamentation reduce to the cubically nonlinear Schroedinger(CNLS) equation in the limit of gentle gradients and weak field intensities. By gentle we mean slowly varying enough so that classical heat transport is accurate, but rapidly varying enough so that ponderomotive effects dominate thermal effects. Weak means that vosc/ve << 1 .

In the mathematical soliton literature[2] it is well known that this Schroedinger equation has quantized soliton solutions which are unstable to collapse, i.e. finite "energy" singularities after finite development (temporal or spatial depending on the physical interpretation). The stationary or collapsing solitons have the same unique energy which in dimensionless units is of order 10. For the filamentation problem, this translates into approximately (Ncrit/No) megawatts for each electron volt of plasma termperature. Except for Ncrit, this is independent of the laser properties.

While the weakness ansatz which led to the above result is violated as collapse developes, the initial devlopement gathers this quantum of power which then plays the role of an effective boundary condition on subsequent development. The choice of other boundary conditions would be unphysical in the sense that you "can't get there from here", where "here" refers to an initially quiescent plasma.

Prior to the breakdown of the weak field ansatz, the classical model of heat transport loses its validity. If one uses the model of Luciani etal[3], then in a physially appropriate heat flux limit one regains the CNLS in which the nonlinearity is boosted by a numerical factor of approximate magnitude 1000*Z (Z is the charge state), and the quantum of power is thereby reduced by this factor.

Aside from the uncertain validity of the above heat flux limit model, static filaments may be dynamically unstable except for special regimes whose existence has not yet been demonstrated to the author's satisfaction.

[1] C.E. Max, Physics of Fluids 19,74(1976).

[2] M.I. Weinstein, Comm. Math. Phys., 87,567(1983).

[3] J.F. Luciani, P. Mora, and R. Pellat, Phys. Fluids 28,835(1985).

Filamentation and Refraction*

E. A. Williams

Lawrence Livermore National Laboratory
Livermore, CA 94550.

By a modification of the WKB technique, the propagation of filaments in inhomogeneous plasma is studied. Numerical and analytical results are compared. The impact of these results on irradiation uniformity issues is 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.

19th Annual Anomalous Absorption Conference
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ENHANCED LASER PENETRATION AND SELF-FOCUSING IN LARGE SCALE UNDERDENSE PLASMAS

E.M. Epperlein

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

Abstract

The propagation of a 0.25 μm wavelength laser beam of Gaussian shape through a large (~ 1 cm) homogeneous high Z underdense plasma has been studied by means of the Fokker Planck code SPARK and a standard fluid code. As a result of strong heat flux inhibition SPARK predicts higher peak temperatures and lower minimum densities. This reduces the plasma opacity and allows for further penetration of the laser beam. The potential for thermal self-focusing is subsequently enhanced, giving rise to even greater beam penetration. Thus, the propagation of the thermal front is considerably greater along the direction of the laser though somewhat less in the perpendicular direction. The reliability of flux limiters to model such phenomena has been investigated.

"This work was supported by the U.S. Department of Energy Division Of Inertial Fusion under agreements No. DE-FC03-85DP40200 and by the Sponsors of the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics."

REVIEW DISCUSSION HR
S. Craxton, Chair

Intensity Structure Issues
W. L. Kruer, Leader

"Mini-Presentations" by
R. Jones
P. Young
A. Mostovych
S. Skupsky

Review Discussion

A Discussion of the Issue of Intensity Structure in Laser Beams*

W. L. Kruer

Lawrence Livermore National Laboratory
Livermore, CA 94550.

Laser beams often have pronounced intensity structure, which can be enhanced by interaction with the target plasma. The effects of this structure on laser plasma coupling, energy transport, x-ray conversion efficiency, and capsule implosions is a significant but poorly understood issue for ICF. Members of a panel will give mini-presentations on the role of beam structure, on filamentation and related phenomena, and on the advantages of laser beam smoothing. About half the time will be reserved for spirited interactions with the audience.

The five minute mini-presentations include:

1. Roger Jones, Los Alamos National Laboratory, "Self-Focusing: What We Have Modeled and What We Need to Model."
2. Peter Young, Lawrence Livermore National Laboratory, "Filamentation Experiments — $ Versus Talks."
3. Andrew ~~Mostovych~~ Schmitt, Naval Research Laboratory, "Effects of Beam Smoothing on Laser Plasma Coupling."
4. Stanley Skupsky, University of Rochester, "Beam Uniformity Considerations for Direct Drive Implosions."

* 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.

MIXED POSTER SESSION H

A study of the effects of numerical damping on SATIN simulations of stimulated Raman scattering

L.V. Powers

KMS Fusion Inc., P.O. Box 1567, Ann Arbor MI 48106

The SATIN code[1] solves the coupled mode equations which describe SBS, SRS, and TPD in inhomogeneous plasma by an implicit finite difference method. A frequency decomposition about a nominal mode frequency ω is employed for the high frequency modes, resulting in a difference scheme with numerical damping proportional to $\delta\omega\delta t$ and numerical dispersion error proportional to $\delta\omega^2$, where $\delta\omega$ is the shift from the nominal center frequency and δt is the time step. The effect of the numerical damping on the mode evolution in the nonlinear regime is a concern.

We have addressed this issue by implementing an implicit, second-order accurate, variable-damping difference scheme[2] to solve the high frequency mode equations. The coefficients of the explicit terms depend on a user-specified parameter θ which can take on values $0 \le \theta < 2$. The resulting numerical damping is given by

$$\nu_n = - \frac{\theta}{(2-\theta)^2} \frac{\delta\omega(2\omega+\delta\omega)}{2(\omega+\delta\omega)} (\delta\omega\delta t)^3$$

and the numerical dispersion is accurate to second order in $\delta\omega$. The expected numerical properties of this scheme are verified by observing the damping of uncoupled modes as a function of the parameter $\delta\omega\delta t$. Spectra of SRS-scattered light and Langmuir waves associated with SRS are compared for various values of the damping parameter, and are compared to results from the first-order scheme.

1. L.V. Powers and R.L. Berger, Bull. Am. Phys. Soc. 30, 1527 (1985).

2. Alex Friedman, "A Second Order Implicit Particle Mover with Adjustable Damping", UCRL-99075 (1988).

19th Anomalous Absorption Conference *Durango (Colorado)* *1989 June 19-23*

1-D non linear SRS/SBS behaviour with Langmuir and sound wave coupling (in inhomogeneous plasma)

G. Bonnaud, D. Pesme†
Commissariat à l'Energie Atomique, Centre d'Etudes de Limeil
94195 Villeneuve s^t Georges Cedex, France
R. Pellat
Centre de Physique Théorique, Ecole Polytechnique, 91128 Palaiseau Cedex, France

Simulations have been performed with a 1-D wave-coupling code (CHEOPS) in order to investigate the stimulated Raman scattering (SRS) behaviour in a plasma with an inhomogeneous density. The long time behaviour of the SRS / SBS coupling has been studied by means of a density profile perturbed by steady-state ion acoustic wave (IAW) fluctuations driven by SBS. The results depend remarkably upon the IAW spectrum and amplitude; a 10% density modulation in a 2 KeV plasma is found to induce absolute SRS-growth in under quarter-critical plasma. The correspondence between the space pattern for SRS growth and the frequency spectrum of the backscattered light is studied; a broad IAW spectrum is found to be necessary for giving rise to intense peaks in the spectral range 0.55-0.65 ω_0. The dependence of these results upon the laser irradiance and density scale length is discussed.

Reference: G. Bonnaud, State Doctorate Thesis, Paris XI University (1989 march)

† Permanent address: Centre de Physique Théorique, Ecole Polytechnique
91128 Palaiseau Cedex, France

19th Anomalous Absorption Conference, Durango, Colorado 1989

Backward and Forward Raman Scattering in long preformed plasmas

F. Amiranoff, C. Labaune, C. Rousseaux, G. Matthieussent*

L.U.L.I Ecole Polytechnique 91128 Palaiseau Cedex France
*Laboratoire P.G.P. Université Paris XI 91405 Orsay Cedex France
Equipes associées au Centre National de la Recherche Scientifique

The scattering of high intensity laser beam in long and homogeneous underdense plasmas through Brillouin and Raman processes can be a problem for future thermonuclear targets. It can lead to the reflection of laser light and to the production of high energy electrons.

A long uniform underdense plasma is created by irradiation of a thin plastic foil (λ = 0,53 µm, τ = 500 ps, I = 10^{13} W/cm^2), the first laser beam is focused along a 2 mm long line. The main laser beam (λ = 0,53 µm, τ = 500 ps, I ~ 10^{15} W/cm^2), with an adjustable delay interacts along this preformed plasma. We present time resolved spectra of Brillouin backscattering, forward and backward Raman scattering. Diode signals are analysed to give a measurement of the amount of scattering for each process. This amount of scattering is compared to the one obtained on imploded foils.

Further experimental study of filamentation in laser-produced plasmas*

P. E. Young, H. A. Baldis[a)], E. M. Campbell, K. G. Estabrook
Lawrence Livermore National Laboratory, USA

Abstract

We have continued an experiment, reported earlier[1], in which we studied ponderomotive filamentation in a laser-produced plasma. The filament-driving beam has a striated intensity profile which allows for identification of density perturbations using schlieren and interferometry. Earlier results have shown evidence of ponderomotive filamentation and have indicated instability thresholds consistent with a simple homogeneous plasma theory. We will present more extensive results in which the peak density and electron temperature of the pre-formed plasma are varied by changing the energy and duration of the plasma-forming beam. By varying the probe beam time relative to the filament driving beam from shot to shot we have investigated the growth of the filaments. The wavelength of the driving beam has also been systematically varied to investigate its effect on filament growth. We have compared filament growth in converging and diverging beams. Filamentation has been observed in both overdense and underdense plasmas.

*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.

a) *National Research Council of Canada, Ottawa, Ontario, Canada*

[1] P. E. Young, *et al.*, Phys. Rev. Lett. **61**, 2336 (1988).

Investigation of Flicker via a Simple Analytical Model*

S. V. Coggeshall, R. D. Jones, W. C. Mead
Los Alamos National Laboratory

Flicker is a dynamic form of laser-plasma self-focusing caused by the continual interaction of small density fluctuations with the laser focusing. Under certain conditions, laser hot spots (beam imperfections or filaments) can cause, through thermal and/or ponderomotive effects, local plasma density fluctuations which can both propagate and convect. As these perturbations move toward the laser, they cause small angle deflections of the light which can shift the positions of the hot spots. New density fluctuations are then produced and the process is self-perpetuating.

LASNEX simulations of reactor-scale plasmas show flicker can occur and cause significant intensity multiplication ($> \times 10$), with implications for hot electron production and x-ray conversion efficiency. The dynamic, unpredictable (chaotic?) nature of the time and spatial distribution of the laser deposition has implications for illumination symmetry in both direct and indirect drive.

We present LASNEX calculations showing the evolution of the phenomenon and introduce a simple, semi-analytic model which contains the feedback of density fluctuations with light focusing. Using this model, we investigate the mathematical properties of the interaction as well as the dependence of the growth/decay time on the interaction parameter.

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

19th Annual Anomalous Absorption Conference
Durango, Colorado
19-23 June 1989

"Shine-Through" Early-Time Phenomena in Laser Fusion Targets.

T. Boehly, D. Bradley and J. Delettrez

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

Abstract

The intense laser light used in laser fusion normally interacts with the plasma formed at the surface of the target. Before the establishment of this plasma, the laser light is incident on the solid surface and may propagate into the target. It has been suggested that this early time "shine-through" and the resultant energy deposition may create non-uniformities and act as a seed for instabilities, resulting in a breakup of the target shell. We present results of experiments in which both glass and polymer targets were irradiated with 600 ps. pulses of 351-nm laser light focused to intensities of 10^{12}-10^{14} W/cm^2 by an f/3 lens. A similar lens at the rear side of the target was used to image the transmitted light onto the slit of a streak camera (time resolution) and onto film (spatial resolution). Our streak camera results show that both glass and plastic targets transmit the early portion of the laser pulse before becoming opaque. We have measured this cut off point for a range of materials and coatings and have also made estimates of the total integrated energy which is transmitted during the initial stage of the laser pulse.

To mitigate the effect of "shine-through" we have coated planar and hemi-spherical targets (made of either glass or polymers) with various layers. We present the results of this study and show the effect of various overcoatings which reduce the shine-through to acceptable levels.

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Effects of Jetting Instabilities on Ablation of High-Z Disks: The Role of Radiation Cooling Instability

W. B. Fechner and N. D. Delamater
KMS Fusion, Inc.
Ann Arbor, Michigan 48106

Recent KMS gold disk experiments for λ_L = 0.53 μm and λ_L = 0.35 μm have demonstrated the formation of "cold" jets, which are so called because they appear in the parts of the corona corresponding to lower laser intensity. Such jets could adversely affect the symmetry of target irradiance. We present 1-D and 2-D simulations aimed at understanding the formation and filling effects of cold jets. The 2-D calculations are performed with HYRAD, a Lagrangian hydrocode with ray tracing, flux limited heat flow, LTE and non-LTE equations of state (EOS), optically thin radiative energy loss and no radiation transport. The 2-D calculations will model cold jetting via at least one class of instability, a "radiation cooling" instability. The 1-D simulations will be performed with DELPHI, a Lagrangian hydrocode with LTE and non-LTE EOS, radiation transport and flux limited heat flow. DELPHI will be used primarily to normalize the energy balance in HYRAD as a function of laser intensity.

H9

19th Anomalous Absorption Conference, Durango, Colorado, June 19-23, 1989.

Modeling and Physical Study of Confined Laser-Matter Interaction

Jean Virmont[1,3], David Devaux[2,3], Rémy Fabbro[2,3], and Jean Fournier[4].

1. Laboratoire P.M.I., Ecole Polytechnique, 91128 Palaiseau cedex, France.
2. Laboratoire L.U.L.I., Ecole Polytechnique, 91128 Palaiseau cedex, France.
3. Laboratoire L.A.L.P., C.R.E.A., 94114 Arcueil cedex, France.
4. P.S.A. Etudes et Recherche, Centre technique Citroën, 78140 Vélizy, France.

1, 2, 3 : Laboratoires du C.N.R.S.

Results are presented concerning the laser matter interaction at intensities around 10^9 to 10^{11} W/cm^2, for metallic targets covered by a transparent layer.

The laser wavelength is 1.06 μm, and the pulse length ranges from 0.6 to 30 ns. The experimental results include (1) momentum, pressure, and absorption measurements, vs. laser pulse intensity and duration, and (2) time resolved measurements of pressure, absorption, and optical emission.

The modeling is done with a 1 D laser code, using Sesame equations of state. It evidences the propagation of a detonation wave into the transparent medium, towards the laser. The numerical results reasonably fit the varous experimental measurements.

ABSTRACT SUBMITTED
FOR THE 19TH MEETING OF THE
ANOMALOUS ABSORPTION CONFERENCE
JUNE 19-23, 1989

BEAM-PLASMA INSTABILITIES IN A DENSE HELIUM PLASMA FOCUS*

F. Begay and I. Lindemuth, Los Alamos National Laboratory

The performance of a dense helium plasma focus has been computed using the two-dimensional computer code MHRDR (Magneto-Hydro-Radiative-Dynamics Research). Results from the computation will be used to interpret experimental results form the University of Maryland plasma focus device [1].

Comparative analysis of the data such as the electron and ion temperature and electron density from the model and the experiment will be reported.

Electron current and velocity distributions from the computations will be used to analyze the role of beam-plasma instabilities in these plasmas. The beam-plasma instabilities can explain the occurrence of measured plasma oscillations in these plasmas.

Dynamic stark emission spectroscopy was used to measure the frequency and intensity of the plasma oscillations. Plasma spectroscopy was used to determine the electron and ion temperature. The moiré-schlieren technique was used to measure the electron density.

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

1. F. Begay et al., Bull. Am. Phys. Soc. 33, 2053 (1988).

Abstract for the
19th Annual Anomalous Absorption Conference
19 June - 23 July 1989

2-D simulations of frequency upshifting of EM radiation using a suddenly created plasma

S.C. Wilks, J.M. Dawson, C. Joshi,
W.B. Mori and A. Banos

Department of Physics
University of California
Los Angeles, CA 90024 USA

It has been proposed that suddenly ionizing a gas in the presence of a monochromatic electromagnetic source wave would cause the frequency of that wave to increase. It is also found that a time-independent, stationary B-field results. Previous 1-D results have been encouraging. In this poster, we address the following issues: 1.) What happens to the upshifted radiation, and the trapped B-field if the plasma ionizes, not "instantaneously" but, over several periods of the source wave?, and 2.) How does the inclusion of a (second) transverse dimension modify the 1-D results? To answer the latter, we simulate various TM and TE modes in a 2-D rectangular waveguide. Finally we begin to test this model and compare with some recent experiments that may have already observed this phenomena, and discuss a currently proposed experiment.

Abstract for the
19th Annual Anomalous Absorption Conference
19 June - 23 July 1989

Relativistic Wave Particle Interaction

R. Williams, C.E. Clayton, C. Joshi
T. Katsouleas and W.B. Mori

Department of Physics
University of California
Los Angeles, CA 90024 USA

The trajectories of relativistic electrons injected into the potentials of 3-D relativistic plasma waves have been calculated using numerical techniques. In particular, we have analyzed in detail the influence of the radial focusing and defocusing fields on the injected electrons. For a plasma wave of given amplitude (accelerating field - accelerating length producer) we calculate the energy spectrum and angular distribution of the accelerated electrons. These results are applicable to current beat wave acceleration experiments at UCLA and elsewhere and to the wake field acceleration experiments at ANL.

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Abstract for the
19th Annual Anomalous Absorption Conference
19 June - 23 July 1989

The Generation of Tunable Radiation Using a Relativistic Ionization Front

W.B. Mori

Department of Physics
University of California
Los Angeles, CA 90024 USA

It is shown that if a light pulse is reflected from a relativistic ionziation front it is simultaneously upshifted in frequency and compressed in duration. The reflection and transmission coefficients are calculated. We find that if the frequency of the incident radiation in the fronts frame (ω_f) is less than the plasma frequency (ω_p) then most of the incident energy remains embedded in the plasma behind the ionization front as a static magnetic field. On the other hand, when $\omega_f > \omega_p$ most of the energy propogates through the newly formed plasma. Examples will be presented.

Work supported by Department of Energy Grant No. DE-FG03-87ER13752.

IONIZATION BALANCE STUDIES IN 20 ps LASER-PRODUCED ALUMINUM PLASMAS

R.L. Shepherd, D. Matthews, C. Keane,
D.Eder, J. Kennedy, T. Phillips,
A. Osterheld,
R. Stewart,
Physics Division,
Lawrence Livermore National Laboratory

G. Charatis, G. Busch, B. Bosch,
E. Gabl,
K.M.S. Fusion, Inc.,
Ann Arbor, Mich.,

April 13, 1989

Recombination x-ray laser schemes are currently being studied because of the potential of scaling them to shorter lasing wavelengths. In such schemes, the plasma ions must strip rapidly, creating a highly non-equilibrium plasma, then cool without drastically reducing the particle density. The plasmas created in this experiment are designed to study the atomic and hydrodynamic physics of recombination plasmas. The plasmas were generated using a 4 to 9 J, 20 ps, frequency doubled $1\,\mu m$ laser pulse focussed to produce intensities of $2.5 \times 10^{14} - 2 \times 10^{15}\ Watts/cm^2$. A variety of target geometries were used in order to vary the hydrodynamic conditions. Pulse width and beam profile data were collected on every shot to monitor the effects of beam quality. Time resolved spectral data were collected using a KAP crystal with a Kentech X-ray streak camera. A small spectrometer was also used to collect spatially resolved, time integrated data. Four frames of UV holographic interferometry data were taken of the expanding plume with 20 ps temporal resolution. Finally, the reflected laser energy was measured as a function of angle with PIN diodes. A general summary of the data and the experiments will be presented. *

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

Abstract Submitted
to the
19th Anomalous Absorption Conference

Pico-second laser generation of harmonics and fluorescence in Noble gases.

Camilo C. Gomez and Rolf M. Sinclair+ (LANL)

We have measured the fluorescence and harmonic spectrum from high density samples of noble gases illuminated with a sub-picosecond laser. The gas samples were provided by a pulsed valve giving densities on the order of 10^{17} - 10^{19} /cc. The laser used was the Los Alamos Bright Source with 20 mJ at 248 nm; the pulse length for the measurements varied between 700 and 300 fsec. The spectroscopy was performed with a XUV flat-field spectrograph with coverage from 10 - 100 nm viewing the sample at 0^o or 90^o to the laser beam. The gases used have been Xe,Ar,Kr,Ne and He. Strong fluorescence is found for the higher Z elements (Xe,Ar,Kr) while little if any for the lower Z elements (Ne and He). The harmonics (preferentially emitted in the foward direction) show a very different behavior: the lower Z elements display a much higher relative conversion efficiency for the higher harmonics (> 5) than the higher Z elements. Detailed results will be presented.

+ Permanent address: National Science Foundation, Wash. D.C.

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

Frequency Shifts of Picosecond Laser Pulses in High Density Plasmas*

O. L. Landen, D. G. Stearns and E. M. Campbell
Lawrence Livermore National Laboratory
P.O. Box 808 M/S L-473
Livermore, California 94550

Abstract

The spectral modification of a probe picosecond laser pulse after reflection from a transient, expanding, high density preformed plasma is presented. Spectra are measured a a function of probe intensity, angle with respect to the target normal, polarization and previously inferred plasma density scale-length.[1] Blue shifts of up to 10Å are observed. The reflected spectra are modelled by considering several frequency shift mechanisms: plasma Doppler shift,[2] plasma flow through the turning point,[3] self-phase modulation of the probe beam upon ionization,[4] and displacement of the turning point upon ionization.

1.) O. L. Landen, D. G. Stearns and E. M. Campbell, "Measurement of the Expansion of Picosecond Laser Plasmas Using Resonance Absorption Spectroscopy" submitted to Phys. Rev. Lett.

2.) H.M. Mitchberg, R. R. Freeman and S. C. Davey, "Behavior of a Simple Metal under Ultrashort Pulse High Intensity Laser Illumination" SPIE Proceedings, Vol. 913 High Intensity Laser-Matter Interactions (1988) p. 159.

3.) T. Devandre, J. R. Albritton and E. A.Williams, "Doppler Shift of Laser Light Reflected from Expanding Plasmas" Phys. Fluids 24 (1981) p. 528.

4.) W. M. Wood, G. Focht and M.C. Downer, "Tight Focussing and Blue Shifting of Millijoule Femtosecond Pulses from a Conical Axicon Amplifier" Opt. Lett. 13 (1988) p. 984.

*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.

Laser matter interaction with a 1 ps laser pulse

J.C. Kieffer[a], P. Audebert[b], M. Chaker, J.P. Matte, H. Pépin
INRS-Energie, C.P. 1020, Varennes, Québec, JOL 2PO, Canada
P. Maine[c], D. Strickland[d], P. Bado, G. Mourou
Ultra Fast Science Lab., Univ. of Michigan, Ann-Arbor, U.S.A.

We present numerical calculations of the interaction of 1 ps laser pulse with solid matter at high intensities. An electromagnetic field solver has been developed to obtain the energy deposition profiles in short gradient scale lengths plasmas. These calculations are used to infer the variations of the density gradient scale length with intensity from absorption data obtained with a 1 ps, 1.06 μm Table Top Terrawatt laser. Simple scaling laws for the plasma parameters will be discussed. The solver has also been used with a 1D hydrocode to calculate the density and temperature profiles of a plasma produced by a high intensity 1 ps laser pulse with and without 30 ps low intensity (10^{-3}) prepulse. Ionization and Emission (for an Al plasma) are calculated with a non L.T.E. time dependent atomic physics. Experimental data on absorption and X-ray spectroscopy are discussed in the light of these numerical results.

a) On leave from Univ. P. Sabatier, UA277 du CNRS, Toulouse, France.
b) Present address: Ecole Polytechnique, Labo PMI, Palaiseau, France
c) Present address: Quantel France, Paris, France
d) Present address: N.R.C. Div. of Physics, Ottawa, Ontario, Canada.

EFFECT OF SPIN ON THE ELECTRON-ION SCATTERING AND HEATING RATE OF A PLASMA IN A VERY INTENSE LASER FIELD

SHAHID RASHID
RPO 9888, P.O.Box 5063
New Brunswick,NJ

An exact Volkov state solution of the minimally coupled Dirac equation is used to calculate the transition rate dR of an electron scattering via a stationary ion in the presence of a very intense laser field. The Coulomb (shielded) interaction is treated as a perturbation in the Born aproximation. Because we are considering high intensity laser field and soft photons, we treat the coherent laser field classically. The question of the electron coupling or decoupling with the laser field is avoided since we assume the final and initial states to be quasifree. This picture is incorporated into the transition rate and a modified Maxwellian distribution is developed. The differential cross section has spin dependent terms. Together with the modified Maxwellian distribution, the heating, W, oft he isotropic part of a quasifree neutral plasma is calculated. In order to simplify, an important transformation is used in the heating rate, W. A new correction factor, F^*, is defined to take into account the mass shift of the electron due to the intense laser field. For $k_BT > 1keV$ and $I < 10^{16}W/cm^2$, a spin dependent term is discovered, given by

$$F' = F + \frac{3k_BT}{2mc^2\, ln(2k_bT/h\nu)}$$

where a new correction factor is defined. This results in a new term not previously known. This effect would be possible to measure with present day laser systems.

Invited Talk (30 minutes)

Recent Progress of Beam-Plasma Interaction Experiments with Heavy Ion Beams

Dieter H.H. Hoffmann

GSI-Darmstadt Postfach 110552,
D-6100 Darmstadt, Germany

Inertial confinement fusion (ICF) requires a very high-power-density deposition of driver energy in fusion pellets. In addition to high power lasers and intense light ion beams, intense heavy ion beams offer an interesting alternative to induce the high energy density in small samples of matter, necessary to drive a fusion pellet or to create a high density plasma environment. With the completion (scheduled for 1989) of the new SIS/ESR accelerator facility at GSI high energy and high intensity heavy ion beams will be available, and open the possibility to heat matter to high temperatures, and reach regimes of pressure and density that are otherwise not easily accessible on a laboratory scale.

High energy heavy ion beams, as they are currently available at the GSI UNILAC are too low in intensity to create a sufficiently dense and hot target plasma in solid matter. Therefore the present experimental program using the heavy ion accelerator at GSI is designed to provide a basic understanding of beam plasma interaction processes. The two major experiments are:

The *Z-Pinch Target Experiment* to measure the energy loss and charge state distribution of heavy ion beams traversing a hydrogen plasma, and

Target experiments, using the intense low energy heavy ion beam from the RFQ accelerator to produce heavy ion induced plasmas in gaseous targets.

Results of the z-pinch experiment show a pronounced enhancement of the of the energy loss of heavy ions in a hydrogen discharge plasma. Compared to cold matter at the same density we find that in a plasma with a high degree of ionization the energy loss is enhanced by more than a factor of two. Measured stopping powers are in good agreement with theoretical predictions for the energy loss of heavy ions in a hydrogen plasma.

The intense heavy ion beam from the RFQ accelerator section has been made available for target experiments. At 45 keV/u it provides a total power of 15 kW and we are using it to irradiate targets and heat them to plasma temperatures, and measure the plasma parameters, temperature and density, as a function of time and input power. Different targets were irradiated to investigate the behavior of heavy ion driven plasmas. New techniques were developed in diagnosing density, temperature and degree of ionization of these plasmas. The results were compared to hydrodynamical model calculations.

ORAL SESSION I
R. Epstein, Chair

Heavy Ions, Beat Waves, & Misc.

Abstract to the 19th Anomalous Absorption Conference
June 19-23, 1989, Fort Lewis College Durango Colorado

Study of preheat by time resolved X-UV imaging of laser illuminated thin foils

R. Benattar & V. Malka, LULI Ecole Polytechnique
91128 Palaiseau cedex, France

We present a diagnostic of temperature measurement of the rear side of laser heated thin foils of aluminium by laser at 0.26μm.

The images of the thin foils are recorded with X-UV Schwartzchild microscopes at several wavelengths. We determine the temperature by doing the ratio of two wavelength emissions at 80 and 40 eV, assuming that the backside emits radiation like a blackbody. Temperature is determined with respect to the foil thickness varying between 5 to 20 μm. X-ray preheat is demonstrated.

Singular Value Decomposition Applied to a Plasma Diagnostic

J.F.McGrath

KMS Fusion, Inc.

Ann Arbor, MI 48106

Film images of a radiating plasma provide important diagnostics for laser-plasma interaction studies. Under the assumption that the plasma is radially symmetric, a slice of the data perpendicular to the axis of symmetry represents a cross-sectional image of the plasma. The film density readings are values of the Abel transform of the radiation profile.

The numerical solution for the radiation profile of the plasma involves the inversion of the Abel transform. The optimal solution to this first kind integral equation is provided in terms of the singular vectors that correspond to the significant singular values of the discretized linear transform. An example using data from an x-ray streak camera illustrates the method.

1–D AND 2–D FOKKER–PLANCK SIMULATIONS OF EARLY–TIME ENERGY DEPOSITION AND TRANSPORT IN LASER–PLASMA EXPERIMENTS

G.J. Rickard, I.R.G. Williams, and A.R. Bell

Imperial College, Prince Consort Road, London SW7 2BZ

Both one– and two–dimensional Fokker–Planck codes have been used to investigate ablation and absorption in laser–plasma experiments at early times ($\leqslant$ 20psecs). In this regime the spatial gradients are of the order of an electron mean free path, and the distance between the critical and ablation surfaces is of the order of the laser inhomogeneity wavelength. The ions are modelled using Lagrangean and Eulerian hydrodynamics in 1–D and 2–D respectively. The variation of ablation pressure with laser intensity and the smoothing of the laser inhomogeneities have been studied. The results have been compared with 1–D and 2–D hydrocodes using the Spitzer conductivity. It is found that there are significant differences between the two models in this regime. In particular, the Fokker–Planck ablation pressure scales less strongly with incident intensity than does the Spitzer pressure. The implications of these results for laser–driven fusion experiments will be discussed.

Effect of Laser Beam Hotspots on Parametric Instabilities in Non-uniform Plasmas

R. L. Berger
KMS Fusion, Inc.
Ann Arbor, MI 48106

High power laser beams have large nonuniformities in intensity (hotspots) either naturally or deliberately induced by such schemes as induced spatial incoherence[1] or random phase masks. The nonuniformities are typically longer in scale along the laser propagation direction than perpendicular to this direction. These effects are complicated if the hot spots move on the time scale of the instability growth rate. Using numerical simulation of the instability in two dimensions, we calculate thresholds and growth rates for parameters of interest.

* Work performed under the auspices of the U.S. Dept. of Energy by KMS Fusion, Inc. under contract DE-AC03-87DP10560.

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1. S. P. Obenschain, et al., Phys. Rev. Lett. **56**, 26, 2802 (1988).

Ion Acoustic Decay Instabilities in Laser-Produced Plasma*

K. Mizuno, P. E. Young+, W. Seka++, R. Bahr++,
J. S. De Groot, R. P. Drake+, and
K. G. Estabrook+
Plasma Physics Research Institute and Plasma Research Group, U.C.. Davis,
LLNL+, and LLE++ (U. of Rochester)

Microwave experiments, and computer simulations have shown that the Ion Acoustic Parametric Decay Instability (IADI) can produce a significant number of hot electrons in a large scale plasma. These hot electrons are a concern in proposed inertial confinement fusion (ICF) studies because they can preheat the target and degrade compression. The ion wave turbulence excited by IADI will also be a source of anomalous resistivity, so that the thermal electrons are strongly heated due to anomalous Joule heating. We have extensively studied the IADI in laser-pellet interactions.

The experiments are performed using the GDL and Omega laser facilities at LLE, and the Janus (Phoenix) and NOVA laser facilities at LLNL. The laser is incident normally onto a planar target (CH, Al, MO, and AU of 50 μm thickness) with a 1 ns FWHM Gaussian pulse and a maximum energy of 120 J. The IADI is studied by monitoring the Stokes sideband of the backscattered (45 degree) spectrum near the second harmonic of the laser light. The time resolved spectrum is obtained using an LLNL streak camera combined with 1/2 m monochrometer (resolution of 1Å and 30 psec).

A well defined Stokes mode excited by the IADI is observed. The threshold decreased as the laser spot size increased. The threshold values reached homogeneous-plasma collisional values, and are quite low (4 ~ 5) x 10^{12} w/cm^2, and (2 ~ 3) x 10^{13} w/cm^2 for 1 and 1/2 μm lasers, respectively. The results are in agreement with LASNEX calculations with a flux limit of f = 0.1. We have also shown that the ionic charge state Z can be measured using the IADI signal without resorting to complicated atomic physics models. The measured values of Z agree fairly well with LASNEX calculations.

*The research and materials incorporated in this work were partially developed at the National Laser Users Facility at the Laboratory for Laser Energetics, U. of R., with financial support from the U.S.D.O.E. under Cooperative Agreement.
The work performed at LLNL is partially supported by the Plasma Physics Research Institute, Dept. of Applied Science, U.C., Davis and LLNL.

OBSERVATIONS ON THE PLASMA WAVE EXCITED BY THE LASER BEAT-WAVE

A E Dangor, A K L Dymoke-Bradshaw, A E Dyson and P Gibbon
Imperial College of Science, Technology and Medicine
London SW7 2BZ, United Kingdom

S J Karttunen
Nuclear Engineering Laboratory, Technical Research Centre of Finland
SF-OO181 Helsinki, Finland

We report observations of a relativistic plasma wave excited by beating two copropagating laser beams at 1.053μm and 1.064μm in a preformed fully ionised hydrogen plasma produced by multiphoton ionisation with a 0.5 μm copopagating beam. The pump beams were of 200 ps duration and focussed to a peak irradiance of 2 10^{14} W cm^{-2} in a 200 μm focal spot with f200 optics. The plasma wave was detected by monitoring the forward scattered spectrum of a fourth copropagating 0.526μm laser beam. The inferred plasma wave density modulation $\delta n/n$ was about 2%. This corresponds to a longitudinal electric field of about 6 10^8 V m^{-1}. The lifetime of the plasma wave was measured to be less than 50 ps. These results are not in agreement with theoretical predictions and suggest that there is some mechanism limiting the growth of the plasma wave. A possible mechanism is the modulational instability (see paper by A R Bell, this Conference).

MODULATIONAL INSTABILITY IN THE IC/RAL BEAT–WAVE EXPERIMENT

A.R. Bell

Physics Dept., Imperial College, Prince Consort Road, London SW7 2BZ, UK.

In recent Beat–wave experiments performed at the Rutherford–Appleton Laboratory (Dangor et al, this conference) a Langmuir wave has been detected with an amplitude $\delta n/n$ of about 2%. Kartunnen has calculated that a value of 9% would be expected if the maximum were limited by relativistic saturation. Recent analytic work (e.g. Pesme et al, 1988) has shown that the ion modulational instability may be important when the Langmuir wave is weakly driven as in the IC/RAL experiment. We present the results of PIC simulations which show that $\delta n/n \simeq 2\%$ is in accord with limitation by the modulational instability. The temporal characteristics of the measured Langmuir wave are in reasonable agreement with simulation.

D. Pesme et al, Laser & Part. Beams, 6, 199 (1988).

19th Anomalous Absorption Conference
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Durango, Colorado

FOCUSSING OF LIGHT WAVES IN BEAT WAVE ACCELERATORS

P. Gibbon

Plasma Physics Group
Imperial College
London, UK

Focussing thresholds are derived for multiple laser beams propagating through an underdense plasma. The effects of relativistic electron quiver motion and their interaction with a plasma beat–wave are considered. When the plasma wave is driven resonantly, the scattering of the pumps by Raman cascading leads to beam divergence. Competition between this process and relativistic focussing yields an *irradiance* threshold of $I\lambda^2 \simeq 2\times10^{17}\,Wcm^{-2}\mu m^2$, which is significantly greater than the usual relativistic power threshold for parameters of interest. It is shown further in numerical solutions that the plasma wave amplitude can *decrease* even when the laser energy is focussed. This can be prevented by driving the plasma wave slightly *below* the plasma frequency, in which case the cascading process *enhances* the focussing. The laser beams may then propagate over an accelerator stage length without significant deterioration of the plasma wave.

Abstract for the
19th Annual Anomalous Absorption Conference
19 June - 23 July 1989

Test Particle Dynamics in Beat Wave Excited Plasma Waves

P. Gibbon
Imperial College, London, U.K.

W.B. Mori
Department of Physics
University of California
Los Angeles, CA 90024 USA

The dynamics of test particles in plasma waves is studied numerically. Test particles are injected into a plasma wave which is solved for numerically using a code[1] which solves the 2-D Beat Wave envelope equations. The code therefore includes cascading, plasma edge effects, rise time effects, dephasing and radial electric fields. Particular emphasis is given to parameters relevant to the UCLA experiment. Work supported by Department of Energy Contract no: DE-AS03-83-ER40120.

[1] P. Gibbon and A.R. Bell, Phys. Rev. Lett. 61, 1599 (1988).

Dr. Charles J. Armentrout
KMS Fusion Inc.
P. O. Box 1567
Ann Arbor, MI 48106

Dr. Hector A. Baldis
Division of Physics M23A
National Research Council
Montreal Rd.
Ottawa Ontario K1A OR6
CANADA
(613) 993-7388

Dr. Hugh C. Barr
National Research Council of Canada
Physics Division, Bldg.
M23-A Montreal Rd.
Ottawa Ontario K1A OR6
CANADA

A. Barrero
E.T.S.I. Industriales
Avda Reina Mercedes
s/n Universidad de Sevilla
Sevilla 41012 SPAIN

Dr. Steven Batha
Laboratory for Laser Energetics
University of Rochester
250 East River Rd.
Rochester, NY 14623
(716) 275-5101

Dr. A. R. Bell
Physics Dept.
Imperial College
Prince Consort Road
London SW7 2BZ
ENGLAND

Dr. Rene Benattar
LULI-Ecole Polytechnique
91128 Palaiseau Cedex
FRANCE
331 69418200 poste 2106

Richard L. Berger
POB 1567,
KMS Fusion
Ann Arbor, MI 48106

Dr. Bandel Bezzerides
Los Alamos National Laboratory
X-1, MS E531
Los Alamos, NM 87545
(505) 667-7450

Thomas Boehly
Laboratory for Laser Energetics
250 East River Rd.
Rochester, NY 14623
(716)275-5101

Guy Bonnaud
GEA Centre d'Eludes de Limeie
94195 Villeneuve-St. George Cedex
FRANCE

Robert Bosch
KMS Fusion Inc.
P. O. Box 1567
Ann Arbor, MI 48106
(313) 769-8500 Ex. 386

Prof. T. J. M. Boyd
Dept. of Physics
University of Wales
UCNW Bangor LL5-7 2UW
Wales UK

David K. Campbell
Los Alamos National Laboratory
CNLS, MS B258
Los Alamos, NM 87545
(505) 667-4073

Robert Cauble
Lawrence Livermore National Laboratory
P. O. Box 5508
Livermore, CA 94550

Dr. M. Chaker
INRS - Energie, Varennes
Quebec JOL2PO
CANADA
(514) 468-7726

George Charatis
18 Northwick Ct.
Ann Arbor, MI 48105
(313) 930-6104

Won Ho Choe
University of Illinois
204 NEL
Urbana, IL 61801
(217) 333-2295

Yung-Ho Chuang
Laboratory for Laser Energetics
250 East River Rd.
Rochester, NY 14623
(716) 275-5101

Chris Clayton
7732 Boelter Hall
UCLA
Los Angeles, CA 90024
(213) 825-8453

Dr. Steven Coggeshall
Los Alamos National Laboratory
X-1, MS E531
Los Alamos, NM 87545
(505) 667-0943

Dr. R. Stephen Craxton
Laboratory for Laser Energetics
University of Rochester
250 East River Rd.
Rochester, NY 14623
(716) 275-5101

Ms. Melissa Cray
Los Alamos National Laboratory
X-1, MS E531
Los Alamos, NM 87545
(505) 667-3038

Dr. Jill P. Dahlburg
Code 4440
Naval Research Laboratory
Washington, DC 20375
(202) 767-6582

A. E. Dangor
Physics Dept.
Imperial College
London SW7 2BZ
United Kindgom

Dr. Chris Darrow
Lawrence Livermore National Laboratory
P. O. Box 808, MS L-473
Livermore, CA 94550

Luiz DaSilva
366 LE Conte Hall
U. C. Berkeley
Berkeley, CA 94720

Norman Delamater
KMS Fusion
P. O. Box 1567
Ann Arbor, MI 48106
(313) 769-8580

Dr. Jacques Delettrez
Laboratory for Laser Energetics
University of Rochester
250 E. River Rd.
Rochester, NY 14623
(716) 275-5374

Douglas Drake
1465 Hiawatha
Jackson, MI 49201
(514) 764-5891

Dr. R. Paul Drake
Lawrence Livermore National Laboratory
P. O. Box 5508, L473
Livermore, CA 94550
(415) 422-6706

Dr. Don DuBois
Los Alamos National Laboratory
P. O. Box 1663, MS B262
Los Alamos, NM 87545
(505) 667-4135

Dr. Mark H. Emery
Naval Research Laboratory
Washington, DC 20375
(613) 993-7393

Dr. Gary D. Enright
National Research Council of Canada
Division of Physics
M-23A, Montral Road
Ottawa, Ontario K1A OR6
Canada

Dr. Eduardo M. Epperlein
Laboratory for Laser Energetics
University of Rochester
250 East River Rd.
Rochester, NY 14623-1299
(716) 275-8295

Dr. Rueben Epstein
Laboratory for Laser Energetics
University of Rochester
250 East River Road
Rocheser, NY 14623

Dr. Walter B. Fechner
KMS Fusion
P. O. Box 1567
Ann Arbor, MI 48106

Dr. Peter Fieldhouse
Building N56,SPE Division
AWE, Aldermaston
Reading RG44PR ENGLAND
(01144) 7356 4111 Ext. 7482

Edward Gabl
KMS Fusion
P. O. Box 1567
Ann Arbor, MI 48106
(313) 769-8500

John H. Gardner
Code 4440
Naval Research Laboratory
Washington, DC 20375

Dr. Paul Gibbon
Plasma Physics Group
Blackett Laboratory
Imperial College
London SW72BZ
01-589 5111 Ext. 6882

Dr. Steven Gitomer
Los Alamos National Laboratory
X-1, MS E531
Los Alamos, NM 87545
(505) 667-5995

Dr. Antonio Giulietti
Instituto de Fisica Atomica E Molecolare
Via del Giardino, 7
56100 PISA, Italy
50-501384

Dr. Phillip D. Goldstone
Los Alamos National Laboratory
P-4/WT, MS F629
Los Alamos, NM 87545
(505) 667-4335

Dr. Camilo C. Gomez
Los Alamos National Laboratory
P-4, MS E554
Los Alamos, NM 87545
(505) 667-7697

Jacob Grun
Naval Research Laboratory
Washington, DC 20375
(202) 707-3379

Dr. Parvey N. Guzdar
Laboratory for Plasma Research
University of Maryland
College Park, MD 20742
(301) 454-3175

Steve Haan
Lawrence Livermore National Laboratory
P. O. Box 5508, L-477
Livermore, CA 94550
(415) 422-4715

Bruce Hammel
Lawrence Livermore National Laboratory
P. O. Box 5508, L-473
Livermore, CA 94550

Dr. D. H. H. Hoffman
GSI-Darmstadt
Postfach 10552
6100 Darmstadt
GERMANY

Dr. Nelson Hoffman
Los Alamos National Laboratory
X-1, MS E531
Los Alamos, NM 87545
(505) 667-3417

Dr. P. A. Holstein
Centre de Limeil
94190 Villeneuve
St. Georges Cedex
FRANCE

Dr. Roger D. Jones
Los Alamos National Laboratory
X-1, MS E531
Los Alamos, NM 87545
(505) 667-5431

Dr. Roy R. Johnson
KMS Fusion, Inc.
3621 South State Road
Ann Arbor, MI 48108
(313) 769-8500

Prof. Chan Joshi
UCLA, Electrical Engineering Dept.
7731 Boelter Hall
Los Angeles, CA 90024
(213) 825-7279

Yoshiaki Kato
Institute of Laser Engineering
Osaka University
2-6 Yamada-OKA, Suita, Osaka 565
JAPAN
06 877-5111

Robert L. Kauffman
Lawrence Livermore National Laboratory
7000 East Avenue
P. O. Box 5508
Livermore, CA 94550
(415) 422-0419

Christopher Keane
Lawrence Livermore National Laboratory
P. O. Box 5508, L-477
Livermore, CA 94550

Kevin J. Kearney
Naval Research Laboratory
Code 4730 Washington, DC 20375
Robert Keck
Laboratory for Laser Energetics
250 East River Rd.
Rochester, NY 14623
(716) 275-5101

J. C. Kieffer
INRS energie, C.P. 1020
Varennes, Quebec J0L2PO
CANADA
(514) 468-7723

Terry Kolber
3 10515-85AUC
Edmonton AB
CANADA T6E 2K5
(403) 492-1066

Dr. William L. Kruer
Lawrence Livermore National Laboratory
P. O. Box 5508, L-472
Livermore, CA 94550

O. L. Landen
Lawrence Livermore National Laboratory
P. O. Box 5508, L-483
Livermore, CA 94550

Wim Leemans
7732 Boelter Hall
UCLA
Los Angeles, CA 90024
(213) 825-8453

John D. Lindl
Lawrence Livermore National Laboratory
P. O. Box 5508
Livermore, CA 94550

Dr. Chuan Sheng Liu
Physics Department
University of Maryland
College Park, MD 20742

Richard A. London
Lawrence Livermore National Laboratory
P. O. Box 5508, L-4777
Livermore, CA 94550
(415) 423-2021

Gregory Luther
Laboratory for Laser Energetics
250 East River Road
Rochester, NY 14623
(716) 275-5101

Dr. Glenn Magelssen
Los Alamos National Laboratory
X-1, MS E531
Los Alamos, NM 87545
(505) 667-6519

Victor Malka
LULI Ecole Polytechnique
91128 Palaiseau
FRANCE
33169418200 poste 2106

Dr. Jean-Pierre Matte
INRS-Energie
Varennes, Quebec JOL 2PO
CANADA
(514) 468-7727

Dr. Dennis L. Matthews
Lawrence Livermore National Laboratory
7000 East Avenue
P. O. Box 808
Livermore, CA 94550
(415) 422-0419

Dr. G. Matthieussent
LPGP-BAT 212
University Paris SUD
91405 ORSAY
FRANCE
69417022

Shahid Rashid
RPO 9888
P. O. Box 5063
New Brunswick, NJ 08903

Bruce Remington
U of C
Lawrence Livermore National Laboratory
P. O. Box 5508 (L-482)
Livermore, CA 94550
(415) 423-3712

Martin C. Richardson
Laboratory for Laser Energetics
250 East River Rd.
Rochester, NY 14623
(716) 275-5101

Harvey A. Rose
Los Alamos National Laboratory
P. O. Box 1663, MS B262
Los Alamos, NM 87545
(505) 667-7347

Dr. Mordecai David Rosen
Lawrence Livermore National Laboratory
P. O. Box 5508, L-477
Livermore, CA 94550
(415) 422-5427

David Ress
Lawrence Livermore National Laboratory
P. O. Box 5508, L-473
Livermore, CA 94556

Dr. W. Rozmus
Dept. of Physics
University of Alberta
Edmonton, Albert CANADA T6G2J1
(403) 492-8486

J. Sanz
Inst. Nucl. Fusion (Denim)
Jose Gutierrez Abascal, 2
28006 Madrid
SPAIN

Andrew J. Schmitt
Code 4730
Naval Research Laboratory
Washington, DC 20375

Wolf Seka
Laboratory for Laser Energetics
250 East River Rd.
Rochester, NY 14623
(716) 275-5101

J. P. Sheerin
KMS Fusion, Inc.
P. O. Box 1567
Ann Arbor, MI 48106-1567

Dr. Robert Short
Laboratory for Laser Energetics
250 East River Rd.
Rochester, NY 14623

Prof. Albert Simon
Laboratory for Laser Energetics
250 East River Rd.
Rochester, NY 14623
(716) 275-5101

John Simpson
KMS Fusion
3621 S. State Rd.
Ann Arbor, MI 48108

Stanley Skupsky
Laboratory for Laser Energetics
250 East River Rd.
Rochester, NY 14623
(716) 275-5101

Dr. John A Stamper
US Naval Research Laboratory
Code 4733
Washington, DC 20375

Dan C. Stearns
Lawrence Livermore National Laboratory
P. O. Box 808, L473
L ivermore, CA 94550

Larry Suter
Lawrence Livermore National Laboratory
P. O. Box 5508, L-477
Livermore, CA 94550

Hideaki Takabe
Institute of Laser Engineering
Osaka University
2-6 Yamada-Oka
Suita Osaka, 565
JAPAN
06-877-5111 Ext. 6533, 6548

Richard Town
Plasma Physics Group
Blackett Laboratory
Imperial College
SW7 2BZ/UK
LONDON
015895111 Ext. 6888

Dr. Thomas E. McDonald
Los Alamos National Laboratory
DDB\ICF, MS E527
Los Alamos, NM 87545
(505) 667-5167

Dr. Joseph McGrath
KMS Fusion
KMS Fusion Inc.
P. O. Box 1567
Ann Arbor, MI 48106

Dr. Colin McKinstrie
Laboratory for Laser Energetics
250 East River Rd.
Rochester, NY 14623
(716) 275-5101

Edgar A. McLean
Naval Research Laboratory
Code 4733
Washington, DC 20375-5000

Dr. William C. Mead
Los Alamos National Laboratory
X-1, MS E531
Los Alamos, NM 87545
(505) 667-1220

Dr. J. Meyer
Department of Physics
The University of British Columbia
VanCouver, BC VGT2A6
CANADA
(604) 228-6577

Dr. David D. Meyerhofer
Laboratory for Laser Energetics
250 East River Rd.
Rochester, NY 14623
(716) 275-5101

Dr. Koenig Michel
LULI Ecole Polytechnique
91128 Palaiseau Cedex
FRANCE
6019411

Dr. Katsu Mizuno
University of California at Davis
Department of Applied Science
Davis, CA 95616
(916) 752-6152

Dr. Juan C. Moreno
Laboratory for Plasma Research
University of Maryland
College Park, MD 20742-3511

Dr. Warren B. Mori
7732 Boelter Hall
UCLA Los Angeles, CA 90024
(213) 825-7514

Dr. Andrew N. Mostovych
Code 4730
Naval Research Laboratory
Washington, DC 20375

Ms. Lesley Pearson
Bldg. N56
SFE Division
AWE Aldermaston
Reading RG74PR
England
(01144) 7356 4111 Ext. 625817512

Dr. Henri Pepin
INRS Energic
Univ du Quebec
CP1020 Vareunes
JOL 2PO Quebec
CANADA
(514) 468-7721

Denis Pesme
Ecole Polytechnique
91128 Palaiseau
FRANCE

Susanne Pfalzner
Hochschulstr 4a
Institut fur Angew Physik
6100 Darmstadt Germany

Linda Verdoorn Powers
KMS Fusion
P. O. Box 1567
Ann Arbor, MI 48106
(313) 769-8500

Prof. Stuart A. Ramsden
Dept. of Applied Physics
Hull University
Cuttingham Road
Hull, HUG7RX
UK
0482 465501

E. R. Tracy
Physics Department
College of William & Mary
Williamsburg, VA 23185
(804) 253-4471

Dr. Robert Turner
Lawrence Livermore National Laboratory
P. O. Box 5508, L-473
Livermore,CA 94550

Dr. David M. Villeneuve
Div. of Physics M23A
Nt. Research Council
Montreal Rd.
Ottawa UNT K1A OR6
CANADA
(613) 993-9975

Dr. Jean Virmont
Laboratoire P.M.I.
Ecole Polytechnique
91128 Palaiseau Cedex
FRANCE

Robert G. Watt
Los Alamos National Laboratory
P. O. Box 1663, MS E554
Los Alamos, NM 87545

Scott Wilks
7732 Boelter Hall
UCLA
Los Angeles, CA 90024
(213) 825-1787

Dr. Edward A. Williams
Lawrence Livermore National Laboratory
P. O. Box 5508, L-472
Livermore, CA 94550

Ian Williams
Plasma Physics Group
Blackett Laboratory
Imperial College
London SW72BZ
UK
01-589-5111 Ext. 6882

Ron Williams
7732 Boelter Hall
UCLA
Los Angeles, CA 90024
(213) 825-8453

John G. Woodworth
Lawrence Livermore National Laboratory
P. O. Box 5508, L-478
Livermore, CA 94550
(415) 422-4508

Dr. Peter E. Young
Lawrence Livermore National Laboratory
P. O. Box 5508, L-473
Livermore, CA 94550

19th Anomalous Absorption Conference
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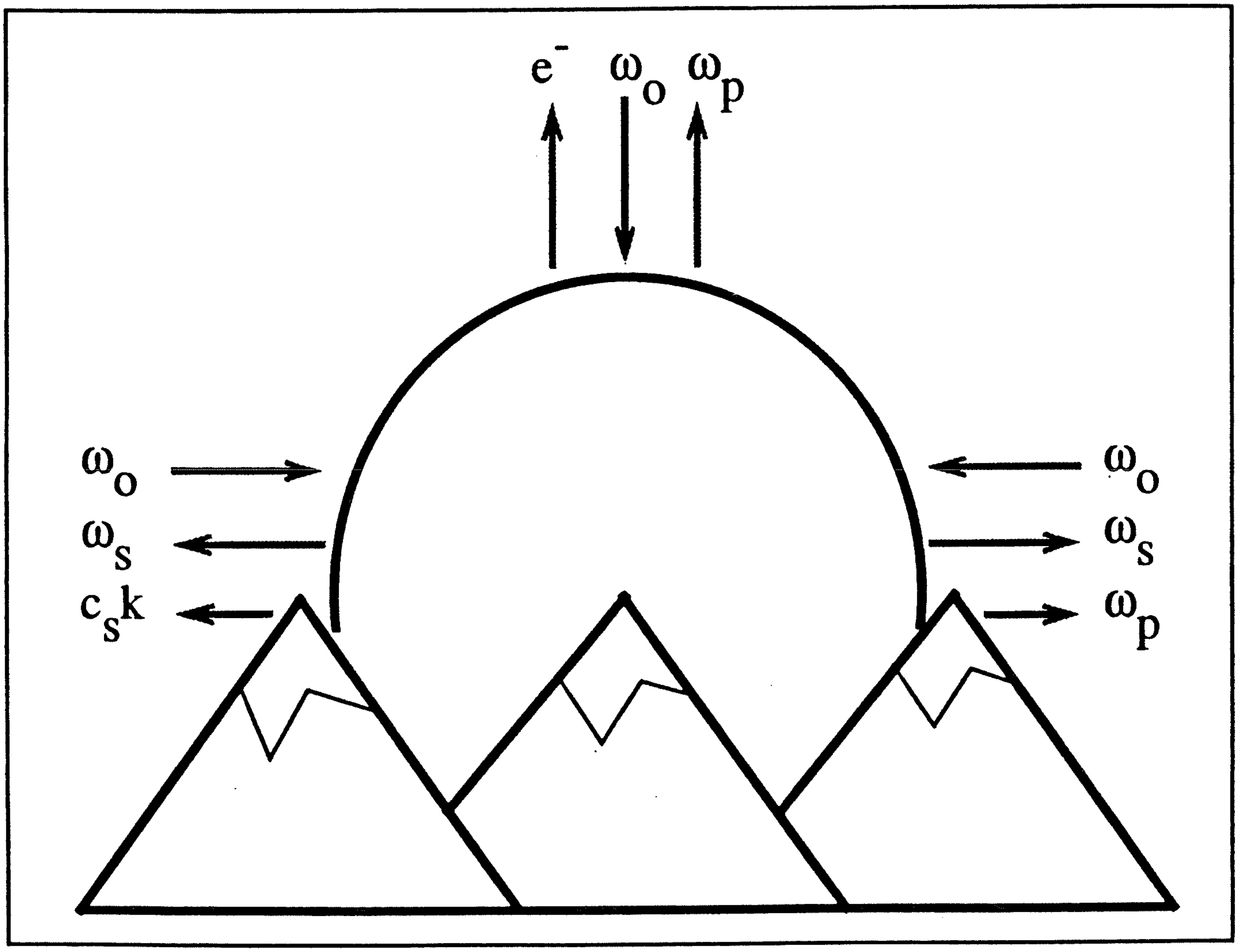
Fort Lewis College, Durango, Colorado



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POST-DEADLINE ABSTRACTS

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1. Filamentation of One-Dimensional Laser Light Perturbations;
   Andrew J. Schmitt

2. Measurement of Electron Temperature in Hot, Solid Density Plasmas;
   Harold M. Milchberg

Filamentation of One-Dimensional Laser Light Perturbations*

Andrew J. Schmitt
Laser Plasma Branch
Plasma Physics Division
Naval Research Laboratory
Washington, DC 20375

Abstract

Recent experiments have investigated laser filamentation in plasmas by using incident light beams dominated by one-dimensional structure[1,2]. The importance of filamentation developing in the direction perpendicular to the applied structure is of theoretical as well as experimental interest. For ponderomotive filamentation, simple theory predicts that a particular mode is selected for fastest growth, and this mode should dominate the filamentation development. For thermal filamentation, the situation is less clear, since the dispersion relation is very insensitive to the wavelength of the perturbation. In either case, however, the filamentation behavior may be significantly altered by the zeroth order applied structure. We wish to address the question of how such beams actually evolve, particularly in regard to the development of orthogonal perturbations. A 3-D laser plasma filamentation code[3] is used to model the development of 1-D structured beams undergoing either ponderomotive or thermal filamentation. Results and comparisons to experiments will be presented.

*Supported by Department of Energy

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Measurement of Electron Temperature in Hot, Solid Density Plasmas

H. M. Milchberg
Institute for Physical Science and Technology
and Department of Electrical Engineering
University of Maryland
College Park, MD 20742

Abstract

The instantaneous mass motion of hot, solid density plasmas is used to infer the electron temperature through the measurement of spectral modifications imposed upon specularly reflected heating pulses.

Summary

The interaction of ultrashort energetic light pulses with solids is of great interest both as a source of picosecond timescale X-ray pulses[1] and as a new and interesting regime of plasma and solid state physics.[2,3]

Recently, Milchberg et al.[2] reported the determination of the electrical resistivity of solid aluminum in the range ~1-100eV, achieved by measuring the reflectivity of energetic 308 nm, 400 fs duration laser pulses from a smooth planar target. The resistivity was parameterized by an auxiliary temperature measurement, which was determined from reflected pulse spectral modifications induced by the increasing value of mass flow velocity of the material interface as the incident laser energy was increased.

The method is ideally suited to the measurement of electron temperature at short times, and gives results at high density which are not dependent upon electron-ion equilibration. In the mode applied here, we measure the pulse shape weighted average in space and time of the electron temperature, but the technique could be easily generalized to a pump-probe configuration.

Energetic, ultrashort UV pulses ($\lambda \sim 308$nm, pulse $\tau \sim 400$ fs, E_{pulse} (max) = 7 mJ) were focused at 45° onto optically smooth aluminum surfaces and the reflectivity of the resulting hot solid plasma and the spectra of the specularly reflected pulses were monitored. The reflected spectra are observed to show a net blue shift and a smoothing and merging of the characteristic $XeC\ell$ peaks as the laser energy is increased. The shift and merging arise from mass motion of heated material away from the original interface during the pulse evolution, with the expanding interface acting as a moving mirror. The modified spectral features are suggestive of the picture that the spectra are convolutions of the laser pulse history and a time dependent Doppler shift set by a time dependent

interface expansion velocity. Thus, if $S_i(\omega)$ is the spectral function of the incident light and $S_R(\omega)$ is the spectral function of the reflected light,

$$S_R(\omega) \propto \int_{-\infty}^{\infty} dt\ I(t)\ S_i(\omega-\Delta\omega(t))R(t) \tag{1}$$

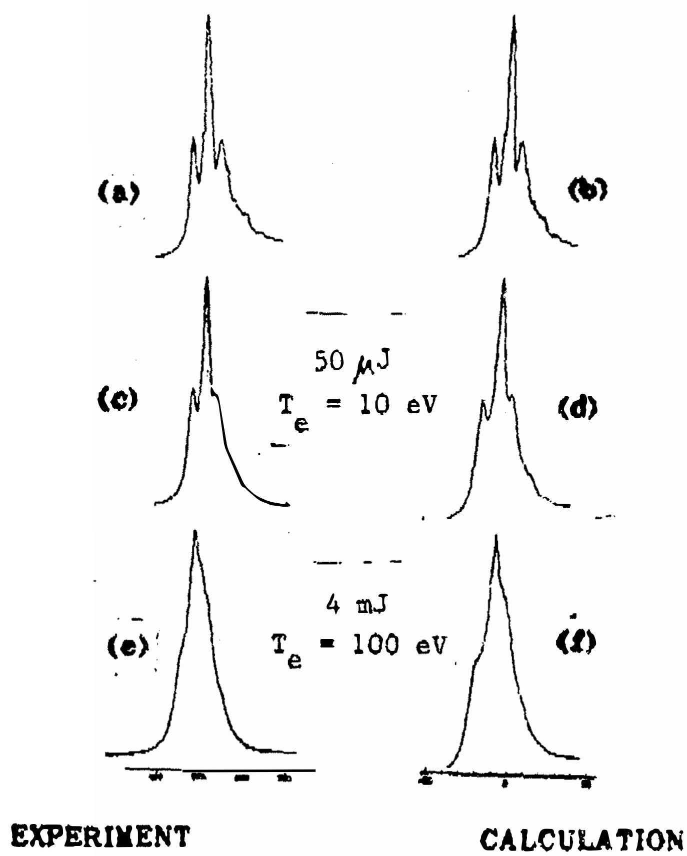
where $\Delta\omega(t) = \frac{2\omega}{c} \cos\theta\, \bar{v}(t)$ is the Doppler shift, θ is the angle of incidence, v(t) is the spatial average velocity of the reflection surface in the beam focus, I(t) is the laser pulse temporal dependence, and R(t) is the reflectivity of the material.

As a function of laser intensity, T_e was first roughly determined by solving for an effective expansion velocity v_{exp}, given the measured shift $\overline{\Delta\lambda}$ in the spectrum's peak and the relation $\overline{\Delta\lambda} = 2 \frac{v_{exp}}{c} \cos\theta\lambda$, where λ is the wavelength at the peak of the XeCℓ spectrum and v_{exp} is related to T_e through an expression for the sound speed.[2]

A better and more illustrative approach giving results similar to the above simple method, is to use equation (1) to reproduce the experimental reflected pulse spectra, where I(t) is modelled as a 400 fs FWHM Gaussian, and $\Delta\omega(t)$ and R(t) are obtained from the data for a sequence of increasingly energetic (0-7mJ) pulse reflections, assuming that the contribution of thermal conduction is relatively small. This latter assumption is justified by the large values of normalized collision frequency, ν/ω, measured in ref. 2 (also see ref. 3).

To do the spectral reconstruction, the unshifted and unperturbed experimental low intensity spectrum was used as S_i in Eq. (1), and is shown in Fig. 1(a) and (b). The spectrum shows the characteristic XeCℓ features. Figures 1(a), (c) and (e) (left side) are the experimental reflected pulse spectra, while Figs. 1(b), (d) and (f) are determined using Eq. (1). The average temperature at each intensity level is obtained by averaging the expression for $\Delta\omega$ (or $\Delta\lambda$) using the sound speed expression for v_{exp} as a function of T_e. The satisfactory agreement demonstrated between the data and the model justifies the picture of the physics, including the relatively small contribution of thermal conduction to the temperature evolution.

FIGURE 1



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