Laser/Plasma Research Laboratory
University of Alberta
Edmonton, Alberta

21st Annual Anomalous Absorption Conference

April 15-19, 1991
The Banff Centre
Banff, Alberta

Twenty-First Annual

Anomalous Absorption Conference

Banff Centre
Banff, Alberta
April 15-19, 1991

Hosted by the University of Alberta

Conference Chair:	Clarence Capjack
Conference Co-Chair:	Robert Fedosejevs
Conference Secretary:	Linda Jacklin

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PROGRAM

Morning Session, Monday, April 15, 8:15 A.M. -------------------- *(A.A. Offenberger, Chair)*

ORAL SESSION - Energy Transport and Hydrodynamics
(15 minutes each)

1O1 Long-Scale-Length Plasmas for the Omega Upgrade;
R.S. Craxton, W.D. Seka, and D.L. Brown.

1O2 Characterization of Long-Scale-Length Plasmas on Omega;
R.E. Bahr, W.D. Seka, R.S. Craxton, D.L. Brown, D.K. Bradley, and S.A. Letzring.

1O3 Further Investigations of the Role of the Rayleigh-Taylor Instability in Bumthrough Measurements;
D.K. Bradley, J.A. Delettrez, and C.P. Verdon.

1O4 Pulse Shaping for NIKE and ICF Targets;
J.H. Gardner, J.P. Dahlburg, M.H. Emery, and S.E. Bodner.

1O5 Shock Dynamics in Multimaterial, Layered Solid Targets;
M.H. Emery and J.H. Gardner.

1O6 Multimode, Ablative Rayleigh-Taylor Simulations in Two and Three Dimensions;
J.P. Dahlburg, J.H. Gardner, and G.D. Doolen.

1O7 Nonlinear Evolution of the Rayleigh-Taylor Instability;
K. Nishihara and H. Sakagami.

1O8 Simulations of Nova Direct-Drive Rayleigh-Taylor Experiments;
S.V. Weber and S.G. Glendinning.

1O9 Three Dimensional Simulations of the Implosion of Inertial Confinement Fusion Targets;
R.P.J. Town and A.R. Bell.

1O10 Effect of Radial Expansion on the Density Evolution of Exploding-Foil Plasmas;
D.S. Montgomery, S.H. Batha, K.S. Bradley, R.P. Drake, K.G. Estabrook, and D.W. Phillion.

Evening Session, Monday, April 15, 7:30 P.M. -------------------- *(W.D. Seka, Chair)*

Review Talk (45 minutes)

1R1 Laser Plasma Issues for Megajoule ICF Targets;
W.L. Kruer.

Mixed Poster Session

1P1 Computational Predictions of Power Balance in Laser-Driven Gold Disks;
D. Ress.

1P2 Planar Indirect-Drive Rayleigh-Taylor Experiments on NOVA;
B.A. Remington, S.W. Haan, S.G. Glendinning, J.D. Kilkenny, and R.J. Wallace.

1P3 Stagnation and Interpenetration of Laser-Created Colliding Plasmas;
S.M. Pollaine, J.R. Albritton, R. Kauffman, C.J. Keane, R.L. Berger, R. Bosch, N.D. Delameter, and B.H. Failor.

1P4 Laser-Driven Hydrodynamic Instability Experiments on Nova;
S.G. Glendinning, J.M. Knauer, S. Weber, C. Verdon, R. Wallace, R. Wilcox, S. Dixit, M. Henesian, and P. Wegner.

1P5 Beam Smoothing on Nova for Direct-Drive Hydrodynamic Instability Experiments;
S.N. Dixit, D.F. Browning, M.A. Henesian, S.G. Glendinning, H.T. Powell, I.M. Thomas, P.J. Wegner, R.B. Wilcox, and B.W. Woods.

1P6 Kinetic Structure of a Collisional Shock Wave in a Fully Ionized Plasma;
M. Casanova, O. Larroche, and J.P. Matte.

1P7 Measurements of the Hydrodynamic Evolution of Nanosecond KrF Laser Plasmas;
R.G. Newton, R. Fedosejevs, R. Rankin, R. Amin, and C.E. Capjack.

1P8 What is the Role of Advanced Fuels in ICF?;
M. Tabak.

1P9 Effects of Interference on Uniformity of Energy Deposition for Laser Driven Fusion;
A.M. Azhar and A.R. Bell.

1P10 The Optimization of Sum-Frequency Generation;
X.D. Cao and C.J. McKinstrie.

1P11 Three-Dimensional Instabilities of Counterpropagating Light Waves;
C.J. McKinstrie, G.G. Luther, and M.V. Goldman.

1P12 Generation of Tunable Radiation from Non-Ideal Ionization Fronts;
W.B. Mori.

1P13 Recent Results from the Relativistic Ionization Front Experiment;
R.L. Savage Jr., C. Joshi, and W.B. Mori.

1P14 Non-LTE Atomic Physics for Laser Target Simulations;
A. Decoster.

1P15 Enhanced Spectral Line Widths from Spherically Expanding Plasmas;
J.C. Moreno, S. Goldsmith, H.R. Griem, and R. Epstein.

1P16 Stimulated Raman Scattering: Collisional Damping and the Long Wavelength Spectral Gap;
H.C. Barr, T.J.M. Boyd, and A.P. Mackwood.

1P17 Up-Shifted Backscatter Raman through Secondary Mode Coupling;
T. Kolber and W. Rozmus.

1P18 Raman Scattering at Near Forward Angles;
S.C. Wilks, W.L. Kruer, K. Estabrook, A.B. Langdon, and S.H. Batha.

-------------------- **Morning Session, Tuesday, April 16, 8:15 A.M.** -------------------- *(J.P. Matte, Chair)*

ORAL SESSION - Ultra-Short Pulse Interactions
(15 minutes each)

2O1 Schlieren and X-Ray Diagnostics of Plasmas Created by a 80 fs Laser;
J.P. Geindre, P. Audebert, J.C. Gauthier, R. Benattar, A. Mysyrowicz, J.P. Chambarret, and A. Antonetti.

2O2 Recent Results from High-Vosc/c Laser-Plasma Interaction Experiments with a 10-TW Glass Laser System;
C. Darrow, M.D. Perry, F. Patterson, C. Coverdale, C. Joshi, C. Clayton, K. Marsh, and W. Mori.

2O3 Ponderomotive Steepening in a Short-Scale-Length Picosecond-Laser-Produced Plasma;
D. Umstadter, X. Liu, J.S. Coe, and C.Y. Chien.

2O4 Characteristics of Ion Emission from 1 ps Laser Pulse Interactions with Short Scale-Length Plasmas;
S. Uchida, H. Chen, Y.-H. Chuang, J.A. Delettrez, and D.D. Meyerhofer.

2O5 Studies of X-Ray Emission from 1 ps Laser-Plasma Interactions;
H. Chen, Y.-H. Chuang, J.A. Delettrez, P.A. Jaanimagi, S. Uchida, B. Yaakobi, and D.D. Meyerhofer.

2O6 Modeling of Resonance Absorption in Hydrodynamic Simulations of 1-ps Laser Pulse Interaction;
J.A. Delettrez, P. Audebert, D.D. Meyerhofer, and S. Uchida.

2O7 X-Ray Emission from High-Temperature Solid Density Plasmas Produced by Intense Subpicosecond Ultraviolet Radiation;
A. Zigler, P.G. Burkhalter, D.J. Nagel, W. Goldstein, A. Barsholom, K. Boyer, T.S. Luk, A. McPherson, and C.K. Rhodes.

2O8 Nonlinear High Frequency Conductivity of Solid Density Plasma;
K. Nishihara, H. Yasui, S. Kato, and K. Mima.

2O9 Static Homogenous Electric Fields in Dense Plasmas;
S. Pfalzner and S.J. Rose.

2O10 Collisionless Absorption of Sub-Picosecond Pulses in Steep-Gradient Plasmas;
P. Gibbon and A.R. Bell.

2O11 Stimulated Backscattered Harmonic Generation by Intense Laser Interaction with Beams and Plasmas;
E. Esarey and P. Sprangle.

2O12 Electron Heating Due to Raman Backscattering in Optically Ionized Plasma Recombination X-Ray Lasers;
S.C. Wilks, W.L. Kruer, A.B. Langdon, P. Amendt, and D.C. Eder.

-------------------- **Evening Session, Tuesday, April 16, 7:30 P.M.** -------------------- *(R. Fedosejevs, Chair)*

Review Talk (45 minutes)

2R1 The Interaction of High Intensity Lasers with Short Scale-Length Plasmas;
D.D. Meyerhofer.

Mixed Poster Session

2P1 Novel Aspects of Intense Laser Pulse Interaction with Plasmas and Beams;
P. Sprangle and E. Esarey.

W7

2P2 Interaction of an Intense Ultra Short Laser Pulse with an Underdense Plasma: Self Focusing and Wakefield;
P. Mora.

2P3 Propagation of Intense Short Laser Pulses through Underdense Plasma;
D. Allen and A.R. Bell.

2P4 Kinetic Simulations of 1 Picosecond Transport Experiments;
J.P. Matte, J-C. Kieffer, M.C. Chaker, H. Pépin, and J. Virmont.

2P5 Nd Laser Beat-Wave Experiments;
J.R. Marquès, F. Amiranoff, M. Laberge, F. Moulin, B. Cros, G. Matthieussent, P. Benkheiri, F. Jacquet, C. Gregory, Ph. Miné, B. Montes, P. Poilleux, and C. Stenz.

2P6 Harmonic Generation in the High-Intensity Limit by the Interaction of a Picosecond Laser with an Underdense Plasma;
X. Liu, D. Umstadter, J.S. Coe, and C.Y. Chien.

2P7 Evidence of Plasma Creation through Tunneling Ionization;
C.E. Clayton, W.P. Leemans, K.A. Marsh, A. Dyson, and C. Joshi.

2P8 Plasma Physics Aspects of Tunnel-Ionized Plasmas;
W.P. Leemans, C.E. Clayton, K.A. Marsh, A. Dyson, and C. Joshi.

2P9 Electrostatic Wake-Field Induced by a Short Laser-Pulse in a Plasma;
D. Teychenné, G. Bonnaud, and J-L. Bobin.

2P10 Multiphoton Ionization Effects in Plasma Waveguides;
R. Rankin, C.E. Capjack, N. Burnett, and P.B. Corkum.

2P11 X-Ray Lasers Based on Optical-Field-Induced Ionization;
P. Amendt, D.C. Eder, and S.C. Wilks.

2P12 Enhanced Absorption of Electromagnetic Radiation in Plasmas Due to Correlated Collisions;
T. Katsouleas, C. Decker, and W.B. Mori.

2P13 Resonant Absorption in a Parabolic Density Profile;
A. Chiron, B. Cros, J. Godiot, G. Matthieussent, and A. Héron.

2P14 Theory of Stimulated Brillouin Scattering in Time-Dependent, Inhomogeneous Media;
R.P. Drake, E.A. Williams, T.W. Johnston, J.S. DeGroot.

2P15 Stimulated Brillouin Backscattering in Large, Underdense Laser Plasmas;
K.S. Bradley, S.H. Batha, D.S. Montgomery, R.P. Drake, K. Estabrook, J. Denavit, and J.S. DeGroot.

2P16 Stimulated Brillouin Scattering Driven by 10 ps Laser Pulses;
Ph. Mounaix, D. Pesme, W. Rozmus, H.A. Baldis, and C. Labaune.

2P17 Interaction Between Stimulated Brillouin Scattering and Filamentation Instability in Plasmas;
P. Frycz, W. Rozmus, J.C. Samson, R. Rankin, and V. Tikhonchuk.

2P18 Three-Dimensional Simulations of Filamentation;
R.L. Berger, B.F. Lasinski, W.L. Kruer, A.B. Langdon, and E.A. Williams.

-------------------- **Morning Session, Wednesday, April 17, 8:15 A.M.** -------------------- *(J. Meyer, Chair)*

ORAL SESSION - Plasma Interactions I
(15 minutes each)

3O1 Nonlinear Interaction Processes in Long-Scale-Length Plasma Experiments on Omega;
W.D. Seka, A. Simon, R.L. Short, R.E. Bahr, R.S. Craxton, D.L. Brown, D.D. Meyerhofer, and L. Zheng.

3O2 The Filamentation Instability in the Presence of More Than One Pump Wave;
R.W. Short.

3O3 Fokker-Planck Simulations of Laser Filamentation in Plasmas;
E.M. Epperlein.

3O4 Dynamics of Hot Spot Filamentation;
H.A. Rose and D.F. DuBois.

3O5 The Effect of Bandwidth and Induced Spatial Incoherence on the Convective Raman Instability;
P.N. Guzdar, C.S. Liu, and R.H. Lehmberg.

3O6 Saturation of Stimulated Raman Forward Scattering: Possible Causes;
S.H. Batha, D.S. Montgomery, K.S. Bradley, R.P. Drake, K. Estabrook, W.L. Kruer, S.C. Wilks, E.A. Williams, and T.W. Johnston.

WD 3O7 Raman Convective Gain for Plasmas with Hot Electron Populations;
T.J.M. Boyd, H.C. Barr, and A.P. Mackwood.

3O8 Beat-Wave Experiment at Ecole Polytechnique;
F. Amiranoff, M. Laberge, J.R. Marquès, F. Moulin, B. Cros, G. Matthieussent, P. Benkheiri, F. Jacquet, C. Gregory, Ph. Miné, B. Montes, P. Poilleux, and C. Stenz.

3O9 Spatiotemporal Dynamics in the Nonlinear Three Wave Interaction;
C.C. Chow, A. Bers, and A.K. Ram.

3O10 Investigation of the Relation Between Two Plasmon Decay and Stimulated Brillouin Scattering and its Impact on (3/2) Harmonic Emission;
J. Meyer and Y. Zhu.

3O11 Temperature Issues in Laser Target Coronas;
J. Meyer and R.P. Drake.

3O12 Transient Effects in Parametric Instability Growth;
E.A. Williams.

5: PM Squash @ Doug.

-------------------- **Evening Session, Wednesday, April 17, 6:30 P.M.** -------------------- *(C.E. Capjack, Chair)*

Banquet

3R1 Toward the Heart of Matter;
E.W. Vogt, Director of TRIUMF.

Business Meeting

-------------------- **Morning Session, Thursday, April 18, 8:15 A.M.** -------------------- (*G.D. Enright, Chair*)

ORAL SESSION - X-Ray Diagnostics and X-Ray Lasers
(15 minutes each)

8:15 4O1 Designs for Coherent Soft X-Ray Lasers;
R.A. London.

8:30 4O2 Designs for Nickel-like Soft X-Ray Lasers Using Fast Pump Lasers (20 < 100 ps);
S. Maxon.

8:45 4O3 A Search for 2p-2s Gain in a Collisionally Excited Ge Plasma;
G.D. Enright, H.A. Baldis, J. Dunn, B. La Fontaine, D.M. Villeneuve, J-C. Kieffer, and H. Pépin.

9:00 4O4 Uniformity Issues in X-Ray Laser Line Focii;
D.M. Villeneuve, H.A. Baldis, J. Dunn, G.D. Enright, B. La Fontaine, J-C. Kieffer, M. Nantel, M. Chaker, and H. Pépin.

9:15 4O5 Plasma Characterization of X-Ray Lasers;
B. La Fontaine, H.A. Baldis, J. Dunn, D.M. Villeneuve, G.D. Enright, H. Pépin, M.D. Rosen, and D.L. Matthews.

9:30 4O6 Model Calculations for Soft X-Ray Lasers in Nickel-like Ions;
A.L. Osterheld, R.S. Walling, W.H. Goldstein, J.H. Scofield, M.H. Chen, B.J. MacGowan, and S. Maxon.

9:45 4O7 Ionization Balance in Photoionized Plasmas;
R.S. Walling, A.L. Osterheld, M.R. Carter, R.E. Stewart, W.H. Goldstein, J.H. Scofield, P.B. Duffy, and H.A. Scott.

10:00 4O8 Detailed Spectroscopy Postprocessor for H-, He-, and Li-like Ions;
C.J. Keane, R.W. Lee, and J.P. Grandy.

10:15 4O9 Monte Carlo Simulation of Complex Spectra for Opacity Calculations; Withdrawn
P. Duffy, M. Klapisch, J. Bauche, and C. Bauche-Arnoult.

10:30 4O10 Simulation of Absorption Spectra from High-Density Implosions of Argon Filled Polymer Shell Targets;
R. Epstein, J.A. Delettrez, D.K. Bradley, P.A. Jaanimagi, R.C. Mancini, and C.F. Hooper.

10:45 4O11 Space-Resolved Spectroscopy of Omega CD Target Implosions;
F.J. Marshall, J.A. Delettrez, R.S. Craxton, and C.P. Verdon.

11:00

-------------------- **Evening Session, Thursday, April 18, 7:30 P.M.** -------------------- (*R.A. London, Chair*)

Review Talk (45 minutes)

4R1 X-Ray Lasers - Progress and Prospects;
M.H. Key.

Mixed Poster Session

4P1 Pulse Shaped Indirectly Driven Implosion Experiments;
D.R. Kania, S.M. Lane, R.E. Turner, S. Hatchett, S. Haan, R. Thiessen, and L. Suter.

4P2 Characterization of Laser-Driven Burn-Through Foils for Radiatively Heated Plasma Experiments;
D.R. Kania, B.A. Hammel, R.W. Lee, M.J. Edwards, P.E. Young, H.N. Kornblum, S.G. Glendinning, S. Dixit, M. Henesian, and H.T. Powell.

4P3 Absorption Measurements of X-Ray Heated Low-Z Materials;
B.A. Hammel, D.R. Kania, R. Doyas, R.W. Lee, C.A. Iglesias, J.F. Seely, U. Feldman, and C.M. Brown.

4P4 Arc Sources for Heavy Ion Fusion Drivers;
D.W. Hewett and H.L. Rutkowski.

Population Inversion in a Muon Catalyzed Fusion Medium and the Possibility of X-Ray Lasing;
Z. Henis and S. Eliezer.

4P6 The Effects of Non-Uniform Laser Beams on Conversion Efficiency;
S.H. Langer.

4P7 Soft X-Ray Production at Low Power, Low Intensity Experiments;
R.L. Kauffman, D.W. Phillion, M.D. Rosen, and C.J. Cerjan.

4P8 Calculated Gain Profiles in Recombination X-Ray Lasers;
M.J. Dunning, P. Amendt, D.C. Eder, and C.J. Keane.

4P9 Development of Short Wavelength X-Ray Lasers for Applications;
L.B. Da Silva, B.J. MacGowan, P.E. Young, D.C. Eder, J.A. Koch, D.L. Matthews, S. Mrowka, and J.E. Trebes.

4P10 Simulations of Soft X-Ray Production for Lithographic Applications;
C. Cerjan.

4P11 X-Ray Spectroscopic Studies of Germanium Plasmas Relevant to X-Ray Laser Research;
J. Dunn, H.A. Baldis, G.D. Enright, B. La Fontaine, D.M. Villeneuve, and J-C. Kieffer.

4P12 Time Resolved X-UV Spectroscopy of the Rear Side of Laser Illuminated Thin Foils at 0.26 mm;
R. Benattar, A. Sezen, and S. Hüller.

4P13 Using X-Ray Diagnostics for Time-Resolved Measurements of Specularly Scattered Laser Light;
R.E. Turner, O.L. Landen, L. Suter, and R. Wallace.

4P14 Non-Local Electron Transport — Effect on Emission Spectra from Laser-Irradiated Plasmas;
R.A. Sacks, J.R. Albritton, and Y.T. Lee.

4P15 The Role of Ion Momentum in Stimulated Raman Scattering;
M. Yu and C.J. McKinstrie.

4P16 Three-Dimensional Alfven Waves in the Magnetosphere;
R. Rankin, J.C. Samson, and P. Frycz.

4P17 In Search for Stable Kinetic Alfven Solitons;
P. Frycz, R. Rankin, and J.C. Samson.

-------------------- **Morning Session, Friday, April 19, 8:00 A.M.** -------------------- (*W. Rozmus, Chair*)

ORAL SESSION - Plasma Interactions II
(15 minutes each)

5O1 Role of Ion Wave Nonlinearities in the Stimulated Brillouin Scattering;
W. Rozmus, M. Casanova, D. Pesme, J-C. Adam, and A. Héron.

5O2 Stimulated Brillouin Scattering from KrF-Laser-Produced Plasma;
M. Fujita, J. Santiago, R. Fedosejevs, and A.A. Offenberger.

5O3 Ion Acoustic Parametric Decay Instability in Laser Produced Plasma with Varying Ionic Charge;
K. Mizuno, R.P. Drake, P.E. Young, R. Bahr, W. Seka, K.G. Estabrook, and J.S. DeGroot.

5O4 Parametric Decay and Caviton Collapse in Ionospheric Radio Wave Modification Experiments;
A. Hanssen and E. Mjoelhus.

5O5 Coexistence of Caviton Collapse and Parametric Decay Cascades in the Interaction of Intense Coherent Radiation with Plasmas;
D.F. DuBois, H.A. Rose, and D. Russell.

5O6 Local Theory of Saturated SRS in 2-D;
D. Russell, B. Bezzerides, D.F. DuBois, and H.A. Rose.

5O7 Global Model of Pure SRS Coupled to Langmuir Wave Turbulence;
B. Bezzerides, H.A. Rose, and D.F. DuBois.

5O8 Observations of Resonant Absorption of Compressional Magnetohydrodynamic Waves in the Earth's Magnetosphere;
J.C. Samson, F. Creutzberg, T.J. Hughes, D.D. Wallis, R.A. Greenwald, and J.M. Ruohoniemi.

5O9 Electron Plasma Wave Breaking and Caviton Formation;
B.S. Bauer and A.Y. Wong.

5O10 Charged Particles as Carriers of the Electrostatic Wave Momentum in Plasmas and their Effects;
B. Amini.

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LONG-SCALE-LENGTH PLASMAS FOR THE OMEGA UPGRADE

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250 East River Road
Rochester, New York 14623

We present designs for long-scale-length plasma experiments to be performed on the upgraded OMEGA laser, based on two-dimensional SAGE simulations. These experiments will extend the parameter regime accessed by the existing OMEGA laser to allow several nonlinear plasma-physics processes to be investigated under realistic reactor conditions. Typical parameters anticipated are L ~ 2 mm, $n_e \sim 10^{21}$ cm^{-3}, and $T_e \sim 2$ keV, although considerable flexibility in these parameters is possible: e.g., plasmas may be obtained with longer scale lengths but lower densities. We also present ray-tracing simulations investigating the feasibility of optical diagnostics such as Schlieren and interferometry.

As in similar experiments performed on the existing OMEGA laser,[1,2] the plasma is generated by exploding a thin plastic foil of finite diameter using a number of primary beams, incident at angles near the target normal. Secondary beams, delayed in time and incident from larger angles, are intercepted by and heat the expanding primary plasma. One or more interaction beams, focused to a high intensity, then irradiates the plasma. The greater energy of the OMEGA Upgrade (~ 30 kJ at 351 nm, as opposed to the present ~ 1.5 kJ) allows reactor conditions to be generated. The greater number of beams (60, as opposed to 24, with each beam containing a ~ 0.75-ns and a ~ 5-ns pulse) allows for greater flexibility in the experimental design. In particular, since the beams are grouped in sets of five (at the small angle of 21^o to a common direction), the geometry is suited to investigating the effect on instability thresholds of multiple overlapping beams.

1. R. S. Craxton and W. Seka, Bull. Am. Phys. Soc. 35, 1944 (1990).
2. W. Seka, R. S. Craxton, R. Bahr, D. Bradley, P. Jaanimagi, J. Knauer, S. Letzring, D. Meyerhofer, R. L. Short, A. Simon, and J. M. Soures, Bull. Am. Phys. Soc. 35, 1944 (1990).

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

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CHARACTERIZATION OF LONG-SCALE-LENGTH PLASMAS ON OMEGA

R. E. Bahr, W. D. Seka, R.S. Craxton, D.L. Brown, D.K. Bradley, S. A. Letzring

good job.

LABORATORY FOR LASER ENERGETICS
University of Rochester
250 East River Road
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We report on long-scale-length plasma experiments carried out on OMEGA over the past year. In these experiments mass-limited CH foil targets are irradiated with several sets of beams. A primary set of eight beams (four on each side) explodes the target while another (delayed) set of eight beams heats the expanding plasma and keeps its electron temperature above 1 keV for an extended period of time. The primary and secondary beams have a wavelength of 351 nm. A tertiary set of beams with a wavelength of 1054 nm can also be used to irradiate the target, with an additional time delay. All beams are defocused in order to irradiate the target or plasma uniformly. An additional, tightly focused beam then acts as an interaction beam. It is incident on the plasma, along the symmetry axis, at a preset time during the expansion phase of the plasma.

Various diagnostics probe the expanding plasma to determine its density and temperature characteristics as a function of time. These diagnostics include time-resolved x-ray spectroscopy, schlieren images taken under various conditions, and visible spectroscopy. The results of these experiments are compared with two-dimensional computer simulations using SAGE, along with a three-dimensional ray-trace post-processor code which is used to simulate the experimental schlieren images. We have found that the computer simulations are in very good agreement with the experimental data, confirming the expected long plasma scale lengths of over 0.5 mm at temperatures in excess of 1 keV and at densities of $\sim 10^{21}$ cm^{-3}.

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

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FURTHER INVESTIGATIONS OF THE ROLE OF THE RAYLEIGH-TAYLOR INSTABILITY IN BURNTHROUGH MEASUREMENTS

D. K. Bradley, J. A. Delettrez, and C. P. Verdon
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The observation of anomalously high burnthrough rates in parylene coated glass microspheres has been attributed[1] to mixing caused by the Rayleigh-Taylor instability which can be seeded by both laser nonuniformities and target imperfections. In a plastic coated glass target, two potentially unstable interfaces exist during the acceleration phase of the implosion; one at the ablation surface and one at the parylene-glass (signature layer) interface. We present new data in which we study the effect of varying the predicted Rayleigh-Taylor growth rates at each of these surfaces, by separately changing both the signature layer material and the ablator material . The scaling of these effects with SSD bandwidth will also be discussed.

1. J. Delettrez, et al., Phys. Rev. A 41, 5583 (1990).

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

Pulse Shaping for NIKE and ICF Targets

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

Laboratory for Computational Physics & Fluid Dynamics

and

S. E. Bodner

Laser Plasma Branch

Naval Research Laboratory, Washington, D.C. 20375

The NIKE laser system being designed and built at NRL will provide a flexible tool to investigate several of the requirements for high gain inertial confinement fusion. Using the echelon free induced spacial incoherence (ISI) technique[1] temporally averaged laser uniformities of less than of few percent peak to valley variation are expected. Such a tool will permit the investigation of highly uniform acceleration of thin targets with a high effective in–flight aspect ratio. The uniform drive will permit the investigation of Rayleigh–Taylor instability for several e–foldings of growth.

Of particular concern to both the NIKE experiments and ICF targets is the effect of pulse shaping on the isentrope of the cold fuel. The NIKE system is capable of contrast ratios of greater than 300 with considerable flexibility in the pulse shape. The pulse shapes used in the NIKE experiments will be similar to those needed in high gain ICF targets. The pulse will be able to model the initial foot and the first three nsec of a high intensity drive but will not have sufficient energy to model the entire drive of a high gain pellet. In this paper we investigate the sensitivity of the isentrope and inflight aspect ratio of NIKE and ICF to details of the rising pulse shape to determine the limits of experimental verifiability. Moderate drive intensities of $1 - 3 \times 10^{14}$ W/cm^2 and contrast ratios of 100 to 300, which approach the range needed for high gain pellets, are investigated.

Seeding the ablator with moderate Z materials to enhance radiation transport has been proposed as a means to ameliorate the Rayleigh-Taylor instability. Preliminary results will be presented on the effect this will have both on pulse shaping and cold fuel isentrope.

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

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

Shock Dynamics in Multimaterial, Layered Solid Targets

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ABSTRACT

The impulsively driven Richtmyer-Meshkov (RM) instability can occur as a result of the shocks generated during the early rise time phase of a reactor-like power law laser pulse. The target surface and any interior material interfaces serve as contact discontinuities and are subject to the original shock, reflected shocks and subsequent rarefactions and compressions. The reflected shocks and rarefactions directly impact target design and pulse shaping. Growth may stem from surface imperfections and/or imperfect beam quality. In addition to inducing seed perturbations for the Rayleigh-Taylor instability, these multiple shocks can induce mix at the material interfaces. One means of reducing the impact of this instability may be to design targets with low density foams and/or high density barriers or to incorporate a truly adiabatic; i.e., shock-free, laser pulse. We will present simulation results of the interaction of uniform and nonuniform shocks on nonuniform and uniform layered, planar targets with our FAST2D LMI Model which now models multiple materials. A volume fraction method has been developed which solves for the advective transport of the distinct species density fraction in addition to the standard FCT hydrodynamic equations for the conservation of mass, momentum and energy. In addition, the equation of state is undergoing modifications which will incorporate melt, elastic-plastic flows and pore compaction in the case of foams.

Multimode, Ablative Rayleigh-Taylor Simulations in Two and Three Dimensions

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From a study of the ablative Rayleigh-Taylor [RT] instability in two and three dimensions, we have found that linear growth is the same for a given perturbation wavenumber $k = \sqrt{k_y^2 + k_z^2}$, irrespective of perturbation shape. Nonlinearly, perturbation shape plays a role. For a given k, the 3D square mode $[k_y = k_z]$ saturates at an amplitude that can be up to 40% larger than that for a 2D mode $[k = \sqrt{2}k_y]$.[1]

In simulations where the target is seeded with many modes of random amplitude and shape, the most destructive modes are found to be the small square ones with higher wavenumbers $[k = 2\pi/(30\ \mu\text{m})]$. Results from an ensemble of 2D and 3D multimode ablative RT simulations indicate that the lowest local values of ρR occur in 3D, at the centers of the smaller square bubbles. These simulations were performed on 50 μm thick planar plastic foils, with single-sided laser illumination, a laser intensity of 3×10^{13} W/cm^2, a laser wavelength of 1.054 μm, and perturbation wavelengths ranging from 20 μm to 120 μm. Significant mode coupling was not observed to occur, in agreement with a multimode analysis.[2]

In this paper we extend the multimode study to 60 μm to 80 μm thick plastic foils accelerated for several nsec by a 0.264 μm wavelength laser at an intensity of 3×10^{14} W/cm^2, to determine the effects of 3D perturbation shape and of possible mode coupling on the hydrodynamic development of targets in the regimes of interest both for the NIKE laser and for direct drive ICF targets.

[1] J. P. Dahlburg and J. H. Gardner *Phys.Rev.A* **41**, 5695, (1990).

[2] S. Haan, *private communication*, (1989).

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Nonlinear Evolution of the Rayleigh-Taylor Instability

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In the stagnation phase of imploding targets in inertial confinement fusion, a perturbation at the fuel-pusher contact surface is Rayleigh-Taylor unstable. Three dimensional Rayleigh-Taylor instabilities in a spherical stagnating system are investigated using of 3d fluid code IMPACT-3D. The saturation of the exponential linear growth is followed by the free-fall phase in which the time evolution of the amplitude is described by $\delta = \eta\ g\ t^2$. The saturation amplitudes and the free-fall coefficients are evaluated for various polar and azimuthal mode numbers. Geometrical dependence of the saturation amplitudes and the free-fall coefficients are also studied by comparing the planer, cylindrical[1)] and spherical systems.[2)]

As the second topic, nonlinear mode coupling of the unstable surface waves are also investigated for the 2d planer geometry. Since the short wavelength modes have large growth rates, high modes grow initially and mode coupling of those modes generates low modes.

1. H. Sakagami and K. Nishihara, Phys. Fluids B2, 2715 (1991).
2. H. Sakagami and K. Nishihara, Phys. Rev. Lett. 65, 432 (1991).

08

Abstract submitted to the 21st Annual Anomalous Absorption Conference

Simulations of Nova Direct-Drive Rayleigh-Taylor Experiments*

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Directly driven Rayleigh-Taylor instability growth experiments being performed on Nova have been simulated using the computer code, LASNEX. Foils with single-wavelength imposed surface perturbations have been driven with a single beam of 0.53 μm light, employing smoothing by spectral dispersion (SSD). In addition to simulating foils with imposed surface perturbations, we have simulated flat foils driven by beams with time-dependent intensity modulation resulting from the Nova implementation of SSD. These simulations show the development of large amplitude modulation of the target from residual intensity nonuniformities. Structure seeded by beam nonuniformity would overwhelm modulation resulting from imposed surface perturbations of sub-micron initial amplitude, but is predicted to develop sufficiently slowly that we expect to observe growth of perturbations with initial amplitudes of several microns. In other Nova experiments, flat foils with an embedded brominated spectroscopic tracer layer are used to infer mass ablation rates. SSD drive is predicted to yield ablation rates in better agreement with 1-D simulations than drive from a beam with random phase plates (RPP) alone. Simulations of foils driven with RPP beams show enhanced ablation rates because modulation of the ablation front increases its surface area. Line emission from the seed is first seen at cold spots in the beam, which create protruding spikes at the ablation front. Simulation results will be compared with early experimental data.

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Three Dimensional Simulations of the Implosion of Inertial Confinement Fusion Targets.

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ABSTRACT

The viability of Inertial Confinement Fusion (I.C.F.) depends crucially on implosion symmetry. A typical I.C.F. target can be characterised as passing through three phases: acceleration, coasting and deceleration. Initially the shell is accelerated inwards: defects in target manufacture and non-uniform irradiation seed the Rayleigh-Taylor (RT) instability on the outer ablation surface. When the shell reaches maximum velocity it coasts inwards. The large spherical convergence can further distort the shell. As the pressure in the filler gas increases so the shell decelerates. In this final phase the shell is again RT unstable, but on the inner fuel-shell interface.

We report here on simulations of the coasting and deceleration phase using PLATO. This is a fully three dimensional spherical hydrodynamics code. In the deceleration phase we find similar linear growth rates, but greater non-linear growth of the RT instability than is found in two dimensions. The enhancement of the non-linear growth is compared to that found by Sakagami†. The effect of the shell thickness is investigated on the evolution of the RT instability.

† H Sakagami and K Nishihara, *Phys. Rev. Letts.* **65**, P432 (1990)

1010

Effect of Radial Expansion on the Density Evolution of Exploding-Foil Plasmas

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Abstract

An experiment is reported that studied the radial expansion of laser-produced, exploding-foil plasmas by varying the initial foil diameter and keeping the foil thickness and laser conditions constant. Results indicate that the initial foil size had a large effect on the evolution of the peak electron density in the plasma. The plasma was preformed by heating a 2 μm thick CH foil with 15 kJ of 351 nm light, in a 2 nsec pulse, that was focused to a 1.0 mm diameter spot. The initial diameter of the foil target varied between 1.5 mm, 2.0 mm and 4.0 mm. The plasma expansion was studied by observing various optical emissions produced by a 527 nm probe beam, the 351 nm heating beams, and by imaging the UV bremsstrahlung emission from the plasma. Measurements of the peak electron density showed similar early-time behavior for all three foil sizes, consistent with a one-dimensional expansion, but large differences were found when the plasma had reached a peak electron density of about 4×10^{20} cm^{-3}, and were attributed to radial expansion. Comparisons of these data are made to 2-D LASNEX simulations.

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REVIEW TALK 1

W.D. Seka, Chair

LASER PLASMA ISSUES FOR MEGAJOULE ICF TARGETS

W.L. Kruer

Invited Abstract submitted to the 21th Annual Anomalous Absorption Conference

LASER PLASMA ISSUES FOR MEGAJOULE ICF TARGETS*

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The next generation U.S. driver is projected to be a glass laser with an output of 1.5-2.0 megajoules of 0.35 μm light. Not only will longer scale-length plasmas be irradiated, but a greater control is desired in order to optimize increasingly sophisticated implosion experiments. Some issues of current concern are discussed, including laser beam incoherence, overlapping beam effects, thermal filamentation, stimulated Brillouin scattering, and the need to complement exploding foil experiments for extrapolation of the coupling physics. Some new regimes are pointed out. Consideration is also given to Raman and Brillouin forward scattering at an angle in extended regions of low density plasma and to detuning as an instability saturation mechanism.

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

MIXED POSTER SESSION 1

Abstract for the 1991 Anomalous Absorption Conference Poster Session —

Computational Predictions of Power Balance in Laser-Driven Gold Disks

David Ress

Laser-irradiated gold disks are now frequently used as a source of x rays. The disks absorb about 90% of incident 350-nm laser light at intensities of a few $\times 10^{14}$ W/cm^2. Approximately 2/3 of the absorbed laser power is converted to x radiation. The remaining 1/3 of the power is dissipated by the coronal plasma evolved from the disk surface. The energy carried by the plasma is divided about equally between electron thermal energy and ion kinetic energy. The detailed time-dependent power balance is predicted by LASNEX one-dimensional disk simulations. Mechanisms are discussed through which the plasma energy can couple to the volume surrounding the laser-driven surface.

1P2

Planar Indirect-Drive Rayleigh-Taylor Experiments on NOVA

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Abstract

A critical issue for laser-driven fusion is the extent to which surface perturbations grow during acceleration in high-gain implosion designs. To address this issue, we have initiated an experimental and theoretical effort at the Nova Laser Facility to study perturbation growth due to the Rayleigh-Taylor instability on planar foils accelerated radiatively by a shaped drive. We have measured the growth of single-mode sinusoidal perturbations in a set of experiments that varied separately the perturbation amplitude, wavelength, and foil thickness. To investigate mode coupling, we have accelerated foils with two modes (wavelengths $\lambda_{1,2}$ = 50 μm, 75 μm) superposed on the surface. As a first attempt at determining the effect of a "broad spectrum" of modes, we have recently accelerated foils whose surface perturbation is the superposition of eight modes (λ_{1-8} = 22.5 - 180 μm) with random amplitudes. Our experimental results and comparisons with 2-dimensional computer simulations will be presented.

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1P3

Stagnation and Interpenetration of Laser-Created Colliding Plasmas

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21st Anomalous Absorption Conference
Banff Center, Alberta, Canada
April 14-19, 1991

Abstract

A KMS laser experiment collides Aluminum (Al) and Magnesium (Mg) plasmas. The measurements include electron density, time and space- resolved Ly_α and He_α lines of Al and Mg, and x-ray images. These measurements were analyzed with a two-fluid code OFIS[1] and Keane's code DSP[2]. The results suggest that at early times, the Al interpenetrates the counterstreaming Mg plasma and deposits in the dense Mg region. At late times, the Al plasma stagnates against the Mg plasma.

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Laser-Driven Hydrodynamic Instability Experiments on Nova

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Laser beam smoothing by means of random phase plates and spectral dispersion of a high bandwidth beam has recently been implemented on one beam of Nova, providing us with a flat-topped beam profile with a residual modulation of $\sigma/\mu = 0.2$. We have begun a series of experiments on hydrodynamic (Rayleigh-Taylor) instabilities in planar foils. The foils (polyethylene samples 20 μm thick with varying imposed initial perturbations) are driven with $\sim 1 * 10^{14}$ W/cm^2 incident 0.53 μm laser light for 3 ns. The targets are radiographed before and during acceleration using a multiple frame gated x-ray pinhole camera (gate time ~100 ps) and an x-ray backlighter target illuminated by a second laser beam. Preliminary data for single wavelength targets (λ=50 μm, a_0=1.5 μm) 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.

Beam smoothing on Nova for direct-drive hydrodynamic instability experiments* S. N. Dixit, D.F. Browning, M. A. Henesian, S. G. Glendinning, H. T. Powell, I.M. Thomas, P. J. Wegner, R.B. Wilcox, and B.W. Woods, *Lawrence Livermore National Laboratory, Livermore, CA 94550.*

Direct-drive inertial confinement fusion (ICF) targets require extremely uniform laser beam profiles to prevent the growth of unwanted hydrodynamic instabilities. Two approaches have been taken to meet beam smoothing requirements of direct-drive ICF -- using random phase plates to break the beam up into fine-scale speckle which the target is able to smooth by thermal conduction and causing that speckle structure to rapidly vary in time to give a time-averaged smooth beam. Implementation of temporal smoothing was achieved using induced spatial incoherence (ISI) at NRL and, more recently using smoothing by spectral dispersion (SSD) at Rochester.

We have implemented beam smoothing on one arm of the Nova laser for investigating the growth of directly-driven hydrodynamic instabilities at 527 nm. These experiments require a nearly flat (± 5%) intensity profile of approximately 600 μm spatial extent and an energy of 4 kJ in a 3 ns pulse. This spatial profile is achieved by: i) inserting random, bi-level phase plates consisting of hexagonal elements in the beam path to transform large scale spatial non-uniformities into small scale speckle; ii).further broadening the focal spot into a 'flat-top' distribution using an optical wedge array and, iii) temporally smoothing the speckle pattern through a spectrally dispersed, randomly cross-phase-modulated beam (noisy-FM SSD).

In order to estimate the expected smoothing, we have developed detailed modeling of the performance of the phase plates, the wedges and the SSD. Our model takes into account the actual distribution of the phase plate elements in the phase plate, and the detailed Nova beam shape including the obscurations and wedges. SSD is simulated using a realistic model for the randomly cross-phase-modulated, spectrally-dispersed broad-bandwidth beam. Calculated far-field speckle patterns and their SSD smoothing characteristics will be presented and compared with the experimentally measured ones.

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

Abstract submitted to the 21st Annual Anomalous Absorption Conference

KINETIC STRUCTURE OF A COLLISIONAL SHOCK WAVE IN A FULLY IONIZED PLASMA

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Ionic non-Maxwellian effects are investigated in a planar collisional shock front which propagates in a fully ionized plasma. The ionic distribution function is solution of a Fokker-Planck equation with the electron-ion coupling taken into account to the lowest order, such that the whole shock structure, including the electron preheating layer and the temperature relaxation layer, may be studied. The Fokker-Planck equation is numerically solved by a direct differencing scheme without the help of Legendre polynomials, allowing large deviations from the standard Maxwellian. Due to the distortion of the ionic distribution function in the preheating layer, the effects of ionic viscosity and ionic thermal conduction are found to be much larger than assumed in usual hydrodynamic plasma simulations with classical transport coefficients.

Measurements of the Hydrodynamic Evolution of Nanosecond KrF Laser Plasmas

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Interferometric measurements have been made of the plasma produced by 1.5ns Brillouin compressed KrF laser pulses on solid aluminum targets at intensities of up to 1 x 10^{14} W cm^{-2}. In particular, the density gradient scale length in the underdense plasma region is measured as a function of time. An evolution from planar to simple stationary spherical flow is observed and compared to both analytic models and 2D numerical simulations. Good agreement is found with 2D numerical simulations and analytic models once the lateral expansion of the plasma is taken into account.

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What is the Role of Advanced Fuels in ICF?*

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The systematics of burn are studied by starting with compressed fuel configurations with ignited hotspots, allowing them to burn, and using the correlations among gain, initial internal energy, escaped energy and tritium utilization. The compressed configurations satisfy pressure balance and the optimized proportions of the Meyer-ter-Vehn-Rosen model. The role of advanced fuels is studied by replacing some of the tritium with deuterium or helium-3 either homogeneously or heterogeneously. There are significant gain penalties for improvements in tritium utilization or neutron loading.

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EFFECTS OF INTERFERENCE ON UNIFORMITY OF ENERGY DEPOSITION FOR LASER DRIVEN FUSION

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A numerical analysis describing the laser rays propagating through the spherical symmetric plasma, energy deposition by inverse bremsstrahlung absorption, and the effects of interference produced by laser rays on absorption is presented. The ray tracing approximation breaks down in the vicinity of the critical density surface where most of the laser energy is absorbed. We have solved the wave equation in 1-D numerically in an inhomogeneous plasma at normal and oblique incidence for a planer target using a linear density profile. The results obtained by the ray tracing solution are compared with the numerical solutions and are found to be in good agreement when a modification in phase at reflection is included. With the improved 2-D ray tracing code for spherical geometry using a generalised range of density profiles[1]. We have examined the effects of interference between incident and reflected rays on absorption. For a single beam the variation in absorption with interference at different positions on a spherical target is considered and the results for the short scale length plasmas indicate some contribution from interference to the nonuniformity of energy deposition.

1) I.N. Ross, J. Phys. D: Appl. Phys., 16 (1983)

1P10

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THE OPTIMIZATION OF SUM-FREQUENCY GENERATION

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In optical mixing experiments involving high-intensity laser beams, the transfer of energy to the product wave(s) can be limited by nonlinear phase shifts which detune the interaction. However, by choosing the linear phase mismatch judiciously, the energy-transfer efficiency can be restored to the Manley-Rowe limit.[1] The idealized solitary-wave analysis, on which this previous result is based, has been generalized. Explicit solutions are found for the equations governing steady-state unidirectional three-wave mixing, for the common case in which two waves are incident on the nonlinear medium and one wave is generated internally. Explicit formulae are given for the optimal linear phase mismatch and the resulting energy-transfer length. As a specific application of the general theory, sum-frequency generation in a uniaxial crystal is considered.

1. C. J. McKinstrie, G. G. Luther, and S. H. Batha, *J. Opt. Soc. Am. B* 7, 340 (1990).

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THREE-DIMENSIONAL INSTABILITIES OF COUNTERPROPAGATING LIGHT WAVES

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A study is made of the three-dimensional instabilities of two counterpropagating light waves in Brillouin-active media. Such instabilities involve from one to four near-resonant electromagnetic sidebands, which interact with each other and the pump waves by scattering from four different sound-wave density gratings. These gratings can be driven either resonantly or nonresonantly. The maximal instability growth rate is determined as a function of the principal-grating wavevector q. By allowing q to have arbitrary magnitude and direction, a unified treatment is given for stimulated Brillouin forward-, side- and back-scattering, and filamentation. In many cases, the maximal temporal growth rate of the four-sideband instability[1,2] exceeds those of the one- or two-sideband instabilities due to scattering from either pump wave by itself, or of the two-sideband phase-conjugation instability. Furthermore, the four-sideband instabilities are usually absolute in nature. Results are presented for instabilities in both finite and infinite media. These instabilities could play an important role in phase conjugation in Brillouin-active media and in inertial confinement fusion.

1. P. Narum, A. L. Gaeta, M. D. Skeldon, and R. W. Boyd, *J. Opt. Soc. Am. B* **5**, 623-628 (1988), and references therein.
2. C. J. McKinstrie, G. G. Luther, and M. V. Goldman;, Papers 2E8 and 8T30, 32nd Annual Meeting of the American Physical Society, Division of Plasma Physics, Cincinnati, Ohio, November 12-16, 1990.

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Generation of Tunable Radiation From Non-Ideal Ionization Fronts

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There has been recent interest in using ionization fronts to generate tunable radiation. The radiation is generated by sending radiation towards either an overdense or an underdense front. Lampe et al.[1] considered reflection from both discontinuous and continuous overdense fronts. Recently, we considered "reflection" from discontinuous underdense fronts.[2] We have extended the analysis to include continuous underdense fronts. We find that the "reflection" and transmission coefficients are unchanged. Both theoretical and simulation results will be presented. In addition we have begun to consider fronts with non-constant velocity and two-dimensional effects. Preliminary results will be presented.

This work is supported by DOE contract no. DE-AS03-83-ER40120 and DOE grant no. DE-FG03-91-ER12114.

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1. Lampe et al., Phys Fluids **21**, 42 (1978).
2. W. B. Mori, UCLA PPG No. 1307, May (1990).

Abstract for the
21st Annual Anomalous Absorption Conference
April 14-19, 1991
Banff, Alberta, Canada

Recent Results from the Relativistic Ionization Front Experiment

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A laser-produced, relativistically-propagating ionization front is utilized to upshift the frequency of source radiation at 34.8 GHz by more than a factor of three to above 116 GHz. The source microwaves are confined in a cylindrical waveguide operating near cutoff such that their group veloctiy is approximately one half the velocity of light in vacuum. This allows us to investigate the behavior of radiation which is initially propagating in the same direction as (forward) and is overtaken by the ionization front as well as initially counter-propagating (backward) radiation.

Theory predicts that the forward wave will be upshifted by a greater amount than the backward wave and that both upshifts will be proportional to the plasma density in the ionization front. The group velocity of the forward wave always increases with the degree of upshift, while that of the backward wave initially decreases, dropping to zero then increasing in the forward direction for large upshifts.

Comparison with theory requires knowledge of the plasma density in the front, which we now measure using a 65 GHz microwave interferometer. Preliminary results are in reasonable agreement with theory, showing the upshift to be proportional to front density with the forward wave dominating in the forward direction and the backward wave disappearing in the backward direction at approximately the predicted density.

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1P14

Non-LTE atomic physics for laser target simulations

Withdrawn

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Simulations of laser experiments require a radiative hydrodynamical code with a non-LTE description of matter.

The atomic physics package Nohel describes a screened hydrogenic average ion. It gives a self-consistent set of non-LTE data : ionization, equation of state, spectral and group-averaged emissivity and opacity (Planck and Rosseland means), for all elements, and for all density and temperature values. The equation of state includes the non-LTE electronic contribution (Zimmerman-More), the LTE ionic equation of state Ioneos (Cowan), and the cold equation of state Panda (Los Alamos). To get the spectral results, the average ion lines and edges are widened into gaussian arrays to represent the statistical fluctuation around the mean : the statistical width is obtained through inversion of the correlation matrix.

The recent absorption spectroscopy experiments in Limeil have been simulated with the radiative hydrodynamical code Chivas-T coupled to Nohel. The spectra so obtained show the absorption structures. However, the use of gaussian envelopes makes it impossible to distinguish between the contributions of different charge states : these spectra cannot replace those from a detailed kinetic code used as a post-processor. But the hydrodynamical code alone is shown to be sufficient, not only to calculate the target density and temperature histories, but also for the temperature diagnostic of (e.g.) germanium from L shell absorption.

1P15

Enhanced Spectral Line Widths from Spherically Expanding Plasmas*

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We have performed high resolution extreme ultraviolet spectroscopic measurements of both spherical expanding plasmas and "planar" expanding plasmas. Spherical plasmas were produced by uniformly irradiating spherical targets with 24 beams from the Omega laser system, while "planar" plasmas were produced by line focus irradiation of slab targets. Direct comparison of spectral lines from these two types of plasmas using the same spectroscopic arrangement shows enhanced broadening of emission lines from the spherical plasmas. This broadening is interpreted as due to motional Doppler shifts from ion expansion velocities. Line profiles are modeled using hydrodynamic code calculations, including opacity effects, and compared to measured profiles.

* Supported by U.S. Department of Energy.
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Stimulated Raman Scattering: Collisional Damping and the Long Wavelength Spectral Gap

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Collisional damping has important consequences for the nature, threshold and spectrum - not to mention control of the Raman instability in inertial confinement fusion targets. Using a full-wave model of stimulated Raman scattering (SRS) we contrast its impact on (a) the absolute growth and (b) the convective gain in hot inhomogeneous plasmas created from a variety of target materials (Z). The model elucidates the qualitative and quantitative differences between SRS occurring at high densities (up to the quarter critical density) and scattering from lower densities near the Landau cut-off. In all cases, the lowest absolute thresholds occur for SRS from the quarter-critical density region, even for high Z plasmas. However, at these densities the sensitivity of resonances to changes in scattered wavelength λ_s or laser intensity is acute, particularly for low Z plasmas. This sensitivity reduces with increasing Z and towards lower densities. Wavelengths distinct from the absolute instability values result only in convective gain. Only within a bandwidth of $\Delta\lambda s \sim 10^{-3} - 10^{-4}\, \lambda s$ of the absolute instability values is gain of $\exp(2\pi)$ or greater possible. At most wavelengths, gain is negligible in low Z cases. These sharp resonances are susceptible to detuning. Such suppression of SRS would be most easily achieved in low Z high density plasma, and could therefore be contributory to the frequently observed long wavelength spectral gap. In high Z targets, this sensitivity is much reduced and, although the absolute instability thresholds are raised in line with the increased collisional damping, large convective gain is achievable at all wavelengths. In this case detuning would be less effective and no long wavelength spectral gap should be apparent.

UP-SHIFTED BACKSCATTER RAMAN THROUGH SECONDARY MODE COUPLING

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In recent experiments up-shifted backscatter Raman has been observed (*S.H. Batha et al , C . Labaune et al*) . Such scattering cannot be described by direct coupling to the pump wave but scattering from secondary wave modes allows up-shifted Raman to be produced . Simulations for up-shifted Raman are preformed using a 1-D fluid code . Included in the code is the coupling of ion and electron modes through the Zacharov equations as well as stimulated Raman and Brillouin backscatter .

Abstract submitted to the 21th Annual Anomalous Absorption Conference

RAMAN SCATTERING AT NEAR FORWARD ANGLES*

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Two dimensional computer simulations, of both Raman and Brillouin forward and near forward scattering, are presented to show the linear and nonlinear behavior of these instabilities in a 1-20 keV temperature, low density ($\sim 0.04\ n_{cr}$) plasma. Modifications of 1-D theory are discussed, as is the angular dependence of the spatial growth rate. The amount of laser energy scattered into various angles is found to be a few percent of the incident laser. The subsequent heating of the electrons is also discussed.

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

ORAL SESSION 2

J.P. Matte, Chair

ULTRA-SHORT PULSE INTERACTIONS

Abstract for the 21st Anomalous Absorption Conference
April 14-19, Banff, Alberta (Canada)

Schlieren and x-ray diagnostics of plasmas created by a 80 fs laser

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A CPM dye laser delivering optical pulses of 80 fs duration at 620 nm with a maximum energy of 1.5 mJ per pulse has been focused onto glass cylindrical fibers with a f/8 lens. The focal spot size was of 10 μm diameter. A weak part of the laser beam was used to create a continuum which was further amplified by a dye amplifier to 400 μj and compressed to 60 fs. This 530 nm laser beam was used as a probe crossing the interaction region at an angle of 90° with respect to the main laser-creating pulse. A Schlieren technique using an imaging lens and a knife edge permitted to get an image of the plasma from the refracted rays of the probe beam which cross the plasma. An optical delay line allowed to record images of the plasma at different times during its expansion. A plasma velocity of several 10^7 cm/s has been deduced from the experimental data recorded at different times. Comparison of images taken from plasmas created on glass and carbon has been done in order to show the effect of the pre-plasma created by the amplified spontaneous emission (ASE) of the laser.

The x-ray emission of the plasma has been analyzed as a function of the amount of ASE by using x-ray diode measurements. An optimum of x-ray emission has been found for a small amount of ASE. Using layered targets, we obtained high resolution spectra of the Kα lines of aluminum and silicon. The analysis of the Kα line emission shows the importance of hot electrons in the interaction physics. Due to the finite transit time of the hot electrons in the absorbing layer, Kα emission cannot be longer than the 80 fs laser pulse. From the observation of the Lyman-α line of the helium-like ion and of its dielectronic satellites, we inferred an electron temperature greater than 300 eV. The shape of the spectrum as a function of the laser intensity and of the thickness of the layer will be discussed.

Recent Results from High-Vosc/c Laser-Plasma Interaction Experiments with a 10-TW Glass Laser System

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and

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Abstract

We will describe the first experimental results from collaborative investigations of high-v_{osc}/c underdense laser-plasma interaction experiments performed at LLNL. The laser system delivers up to about 6 J in a 750 Fsec transform-limited pulse. After propagation to the experimental area, the beam is focused to a near-diffracton-limed spot containing approximately one-half of the original 6 J for a peak intensity in excess of 10^{18} W/cm^2(1) The interaction region consists of a vacuum chamber back-filled with gas (0.1 - 10 Torr of N_2 or He) or a high-density gas jet ($n_{neutral} = 10^{17} - 10^{19}$ cm^{-3}). The spectra of the incident and transmitted laser light are monitored on a shot-to-shot basis for signatures of relativistic-self-focusing-induced pulse erosion (spectral boadening) and self phase modulation (spectral shifts and other modifications). We will attempt to reconcile the results with a variety of current phenomonological and theoretical processes for both collective and atomic processes.

(1) F. G. Patterson and M. D. Perry, sub. to J. Opt. Soc. Am.

* 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.

Ponderomotive Steepening in a Short-Scale–length Picosecond-Laser–Produced Plasma *

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High-density plasmas produced by the interaction of short-pulse lasers with solid targets have been proposed as candidate coherent x-ray sources. Large absorption of laser light and rapid cooling of the plasma—both of which are required for this scheme to work—depend strongly on the evolution of the electron-density profile during the laser pulse. We report experimental and theoretical results indicating that when the quiver energy of the electrons exceeds their thermal energy, the ponderomotive pressure of the laser significantly modifies the plasma density profile. The laser-plasma interaction is described theoretically by the one-dimensional two-fluid conservation equations of mass density, momentum and energy. These equations are coupled to a collisional radiative model for the ionization stages, a modified Spitzer-Harm model for heat conductivity, and the Helmholtz wave equation for the electric field. The experimental diagnostic of the plasma motion is spectroscopy of the Doppler-shifted reflected laser light. Unlike previous studies, our investigation of steepening is in a regime in which the plasma scale-length is much less than the laser wavelength.

*Work performed at the NSF Center for Ultrafast Optical Science, University of Michigan.

21st Annual Anomalous Absorption Conference
Banff, Alberta, Canada
April 14-19, 1991

CHARACTERISTICS OF ION EMISSION FROM 1 PS LASER PULSE INTERACTIONS WITH SHORT SCALE-LENGTH PLASMAS

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The characteristics of ion emission from the interaction of 1 ps, 1 μm 10^{15} W/cm^2 laser pulses with short scale-length Al plasmas (density scale-length ~ 0.01 laser wavelength λ_L) are studied. Charge collector arrays record the spatial distribution of ion current produced from both long ($\lesssim \lambda_L$) and short scale-length plasmas. The plasma scale-length is altered by turning the pre-pulse on and off. We have found that a strong high energy ion flux is emitted from short scale-length plasma irradiated by p-polarized light while no such ions are produced in other cases. These ions have velocities of order of 10^8 cm/s and are emitted within a very narrow cone angle (5° half angle) along target normal direction. Layered targets with K_α emission layer have been used to measure the number and the temperature of hot electrons produced in these plasmas. Possible mechanisms for these experimental observations are discussed.

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April 14-19, 1991

STUDIES OF X-RAY EMISSION FROM 1 PS LASER-PLASMA INTERACTIONS

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The x-ray and EUV emission for the plasma produced by the interaction of 1 ps, 1 μm, laser pulses with moderate and high Z targets is investigated using high resolution, time-integrated spectrographs, filtered x-ray PIN diodes, and an x-ray streak camera.

The intensity contrast of the incident laser pulse is found to have a significant effect on the x-ray conversion efficiency. When the short pulse interacts with a solid target in the absence of a preformed plasma, the keV x-ray emission is reduced by more than an order of magnitude. The characteristics of the x-ray emission on the temporal characteristics of the laser pulse, the angle of incidence and polarization, and on the target material will be presented and will be directly compared with the results of the 1-D hydrodynamic code, LILAC.

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21st Annual Anomalous Absorption Conference
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MODELING OF RESONANCE ABSORPTION IN HYDRODYNAMIC SIMULATIONS OF 1-PS LASER PULSE INTERACTION

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There is strong evidence that resonance absorption plays a major role in the interaction of a 1-ps laser pulse with a plasma in which scale lengths comparable to the laser wavelength have been produced by a prepulse or a pedestal. This evidence comes from two observations at intensities near 10^{15} W/cm^2: the collisional absorption fraction computed from the solution of the one-dimensional wave equation in a hydrodynamic code cannot account for the measured absorption fraction, and the signatures from suprathermal electrons, hard x-rays, and fast ions have been observed in experiments. While the fraction of the incident energy absorbed by resonance absorption can be added to a ray-trace model, it is not as easy to include into the solution of the wave equation. We present an attempt to improve the modeling of resonance absorption by computing the electron plasma wave coupled to the incident electromagnetic wave. Landau damping is included as an absorption channel. Wave-breaking is modeled roughly by limiting the electron plasma wave. Results of the simulation are compared to experimental results.

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X-RAY EMISSION FROM HIGH-TEMPERATURE SOLID DENSITY PLASMAS PRODUCED BY INTENSE SUBPICOSECOND ULTRAVIOLET RADIATION*

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ABSTRACT

Subpicosecond-high-peak brightness lasers capable of delivering focal intensities greater than 10^{16} W/cm^2 permit the generation of high temperature plasmas from solid targets. Studies of M_gF_2, BaF_2, and SiO_2 targets have revealed several important characteristics of the x-ray emission produced from these materials. This includes the generation of strong spectra in the kilovolt range and an experimental determination of the energy penetration depth. LASNEX simulations are found to be in general accord with the experimental results.

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Nonlinear High Frequency Conductivity of Solid Density Plasma

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The interaction of an intense ultrashort laser pulse with matter has recently attracted much interest. If a pulse duration of a laser light is so short that no significant hydrodynamic expansion of a matter takes place, the electric field of a laser interacts directly with a solid density matter. We evaluated the nonlinear high frequency conductivity of solid density plasmas and estimate absorption efficiency as a function of the intensity, both analytically, and using of 3d particle code "SCOPE".

Since ions are strongly coupled in such plasmas, the ion-ion correlation is described by the hypernetted-chain (HNC) equation. On the other hand, the electron-ion correlation is treated by the linear response theory. The quiver velocity and excursion length are finite in comparison with the electron thermal speed and shielding distance respectively.

In the 3d two component (electron and ion) particle code "SCOPE (Strongly COupled plasma ParticlE code)", short range forces are calculated by using a direct particle-particle summation over spatially localized forces and long-range forces by particle-in-cell method.

Static homogenous electric fields in dense plasmas

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A numerical solution of a two-dimensional Thomas-Fermi equation will be presented to investigate the influence of static electric fields on atoms and ions in dense plasmas. For strong fields the usual perturbational treatment is inadequate because the atoms try to compensate the effect of the applied field. The statistical method has the advantage that high-Z materials as well as high-density effects can be investigated. Calculating the temperature-independent case the ionization processes are multiphoton and pressure ionization only. It will be shown in what density region multiphoton ionization dominates and an upper limit of the ionization degree caused by both processes is given over a wide range of densities.

2010

Collisionless absorption of sub-picosecond pulses in steep-gradient plasmas

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Oblique incidence laser-plasma interaction can be studied cheaply with electromagnetic PIC simulation by first making a simple velocity transformation to a frame in which $k_y = 0$. This reduces the system to 1 spatial and 2 velocity dimensions (instead of the 2D system normally required for resonance absorption). Previous results of long scale-length absorption are reproduced at a fraction of the computational cost. In the short scale-length case ($L/\lambda < 0.1$), high absorption is found with an intensity scaling different to the electrostatic model of Brunel (Phys. Rev. Lett. **59**, 52 1987). Systematic studies of absorption will be shown over a range of angles, density scale-lengths and intensities.

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STIMULATED BACKSCATTERED HARMONIC GENERATION BY INTENSE LASER INTERACTION WITH BEAMS AND PLASMAS*

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Recent technological advances have made possible compact terawatt lasers which yield high intensities ($> 10^{18}$ W/cm^2), modest energies (> 1 J) and short pulses (< 1 ps). These high intensities lead to many new and interesting laser–plasma and laser–electron beam interaction phenomena.[1] This paper discusses one such phenomenon, the generation of coherent backscattered radiation in the interaction of intense laser pulses with electron beams and plasmas. For sufficiently intense incident laser fields, the electron quiver velocity becomes highly relativistic. The high laser intensity, along with the induced nonlinear relativistic electron motion, allows for the generation of stimulated backscattered harmonic radiation. In the interaction of an intense laser pulse with a counterstreaming electron beam, stimulated backscattered radiation is produced via a free electron laser (FEL) mechanism and the resulting radiation will experience a relativistic doppler upshift. Hence, a laser–pumped FEL may utilize both the harmonic upshift as well as the doppler upshift in order to generate radiation at short wavelengths. Backscattered harmonic radiation from stationary plasmas may also occur, in which radiation is generated at odd multiples of the fundamental laser frequency. The backscattered harmonic radiation from a plasma is the result of a nonlinear Raman instability mechanism. These mechanisms for producing backscattered harmonics may provide a practical source of coherent radiation in the XUV regime.

*Support by ONR and DOE.

[1]P. Sprangle, E. Esarey and A. Ting, Phys. Rev. Lett. **64**, 2011 (1990); Phys. Rev. A **41**, 4463 (1990); A. Ting, E. Esarey and P. Sprangle, Phys. Fluids B **2**, 1390 (1990).

Abstract submitted to the 21th Annual Anomalous Absorption Conference

ELECTRON HEATING DUE TO RAMAN BACKSCATTERING IN OPTICALLY IONIZED PLASMA RECOMBINATION X-RAY LASERS*

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We report on simulations studying the electron heating arising from the Raman backscatter (SRBS) that occurs when a short ($\sim$ 50-100 fSec), intense ($I \sim 2 \times 10^{17}$ W/cm^2) laser pulse is focused into a plasma, or a neutral gas which quickly becomes a plasma due to multiphoton ionization. Review of the usual SRBS growth rate and associated electron heating will be given, followed by a discussion on how this theory is modified for short pulses. In particular, we discuss how the bandwidth $\Delta\omega \sim 2\pi/\tau_{\rm pulse}$ of the pulse can help to quench the instability, hence allowing for cooler plasma temperatures. It is found that the pump laser be required to have short wavelength ($\leq$ 1/4 micron) and pulse length $\leq$ 100 fSec, in order for the plasma temperature to remain low. This is an important consideration for recombination x-ray lasers employing short pulse drivers, as heating greatly decreases the efficiency of the laser medium.

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

REVIEW TALK 2

R. Fedosejevs, Chair

THE INTERACTION OF HIGH INTENSITY LASERS WITH SHORT SCALE-LENGTH PLASMAS

D.D. Meyerhofer

21st Annual Anomalous Absorption Conference
Banff, Alberta, Canada
April 14-19, 1991

THE INTERACTION OF HIGH INTENSITY LASERS WITH SHORT SCALE-LENGTH PLASMAS

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Over the past few years, the peak intensity of short pulse lasers has been increased and the intensity contrast has been improved. The interaction of these laser pulses with solid targets occurs under conditions where the density scale length (L_n) can be much shorter than the laser wavelength (λ). These interactions lead to the possibilities of producing solid density plasmas and short, intense, x-ray bursts with relatively compact lasers. The presence of the short scale-length plasma leads to new absorption mechanisms and models. The propagation of the laser pulse cannot be treated by a WKB analysis and the penetration of electromagnetic energy into the evanescent, supra-critical, density regime becomes an important part of the absorption physics. The short scale-lengths of the plasma coupled with the high intensity laser fields lead to the possibilities of resonance absorption and other mechanisms for absorption of the laser energy into the plasma. In addition, the short scale-lengths lead to rapid cooling through thermal conduction and expansion.

This talk will review some of the experimental and theoretical work in the area of short-pulse, high intensity laser plasma interactions, with an emphasis on mechanisms for the absorption of laser light and on energy dissipation.

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

MIXED POSTER SESSION 2

NOVEL ASPECTS OF INTENSE LASER PULSE INTERACTION WITH PLASMAS AND BEAMS*

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The interaction of ulta–high power laser pulses with plasmas and electron beams is rich in a variety of wave–particle phenomena.[1] These phenomena become particularly interesting and involved when the laser power is high enough to cause the electron oscillation (quiver) velocity to become highly relativistic. Some of the interesting laser–plasma processes that are discussed include (i) relativistic optical guiding of the laser pulse, (ii) excitation of coherent radiation at harmonics of the fundamental laser frequency, (iii) generation of large amplitude plasma waves (wakefields), (iv) frequency upshifting of laser pulses by ionization fronts and (v) radiative cooling of electron beams by intense laser pulses.

*Support by ONR and DOE.

[1] P. Sprangle, E. Esarey and A. Ting, Phys. Rev. Lett. **64**, 2011 (1990); Phys. Rev. A **41**, 4463 (1990); A. Ting, E. Esarey and P. Sprangle, Phys. Fluids B **2**, 1390 (1990).

2P2

21st Annual Anomalous Absorption Conference
April 15-19, 1991, Banff, Alberta, Canada

INTERACTION OF AN INTENSE ULTRA SHORT LASER PULSE WITH AN UNDERDENSE PLASMA : SELF FOCUSING AND WAKEFIELD

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We study the interaction of an ultra short laser pulse of high intensity with an underdense plasma for laser pulse duration of the order of ω_{pe}^{-1}. The laser propagation and the electron plasma response are self consistently solved with a 2 D time-dependent numerical calculation which includes the mass increase of the electrons caused by their relativistic motion in the laser wave, and the modification of the electron density resulting from the ponderomotive force. We observe the free diffraction of the front of the laser pulse,[1] while the main part of the pulse experience self focusing and defocusing effects associated with the electron plasma oscillations. We also calculate the resulting time dependent wakefield.

1 P. Sprangle, E. Esarey, and A. Ting, Phys. Rev. Lett. **64**, 2011 (1990).

21st Anomalous Absorption Conference, Banff, April 14-19, 1991
Abstract of Poster Paper

PROPAGATION OF INTENSE SHORT LASER PULSES THROUGH UNDERDENSE PLASMA

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We examine the way in which a short relativistically-intense laser pulse distorts as it passes through an underdense plasma with electron density in the range 0.001-0.1 times the critical density. The pulse-length is matched to half the plasma period as required in the laser wake-field accelerator. Calculations with a 1D wave-envelope code show the peak amplitude of the pulse rising as it propagates. The peak moves towards the rear of the pulse leaving a gentle ramp in front of it. This is confirmed by PIC code simulations. We also find that ripples develop on the leading ramp. This curious effect is not easily confirmed with a PIC code because of the large grid-size, propagation time and number of particles needed for a realistic simulation.

2P4

21st Annual Anomalous Absorption Conference

April 14 - 19
Banff Centre, Banff, Alberta
Canada

ABSTRACT

KINETIC SIMULATIONS OF 1 PICOSECOND TRANSPORT EXPERIMENTS

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In a recent series of picosecond interaction experiments with multi-layered targets, at 0.53 and 1.06 microns, K-shell line spectra (He-like and K-alpha) were used to infer the state of the plasma and to characterize the transport physics. Electron kinetic simulations were performed with our code "FPI", in conditions relevant to these experiments. In agreement with observations, the simulations indicate that helium-like lines are emitted from high density plasma, and - because of the very steep gradients which exist in this situation - significant numbers of electrons coming from the hot plasma pre-heat the cold plasma, thus producing k-alpha emission. We will also address the 1.06 micron experiments, where the presence of a prepulse changes the physics considerably.

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Nd Laser Beat-Wave Experiments

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* Laboratoires associés au CNRS

The beating of two copropagating laser beams in a plasma generates a plasma wave which can accelerate electrons to high energies. We are performing experiments using a two-frequency Nd glass laser. The two amplified YAG (λ=1.064 μm) and YLF (λ=1.053 μm) oscillators deliver 10 J each in 100 ps pulses. These two copropagating laser beams are focussed in H_2 or D_2 gas at about 3 Torrs to achieve the resonant electron density near 10^{17} cm^{-3}. We diagnose the produced plasma waves by time resolved Thomson scattering at 0° and 30°.

Harmonic Generation in the High-Intensity Limit by the Interaction of a Picosecond Laser with an Underdense Plasma *

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Modest power lasers interacting with a neutral gas have been observed to produce coherent harmonic radiation (up to the 61^{st} harmonic) at odd multiples of the fundamental laser frequency[1]. This is a result of the laser field causing the bound electrons to oscillate in the anharmonic atomic potential. Laser powers exceeding 10^{13} W/cm^2 lead to ionization of the gas and to the production of unbound electrons in the high-intensity, long-wavelength limit[2]. If the laser pulse is sufficiently intense, the plasma electron mass becomes modulated because of nonlinear relativistic effects[3]. We report the observation of harmonics (including the second harmonic) in this limit using a high-intensity (10^{16} W/cm^2) glass laser ($\lambda = 1$ μm) interacting with various gases.

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*Work performed at the NSF Center for Ultrafast Optical Science, University of Michigan.

[1]J.C. Miller *et al.*, Phys. Rev. Lett. **45**, 114 (1980); M. Ferray *et al.*, J. Phys. B **21**, L31 (1988)

[2]F. Brunel, J. Opt. Soc. Amer. B, **7**, 521 (1990)

[3]P. Sprangle, E. Esarey and A. Ting, Phys. Rev. Lett. **64**, 2011 (1990)

Abstract for the
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Evidence of Plasma Creation through Tunneling Ionization

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Tunneling ionization is essentially the low frequency limit of multi-photon ionization (MPI). As in MPI, the produced plasma has in principle quite predictable properties. Not just density and temperature, but the complete 3-dimensional electron velocity distribution function can be calculated for a given laser intensity and focal conditions. In a single atom regime it has been verified[1] that electrons are created with a polarization-dependent DC-drift velocity, consistent with a tunneling ionization model. Generation of odd harmonics of the ionizing laser frequency laser frequency during the ionization process has been predicted.[2] In our experiment a high intensity ($\approx 10^{15}$ W/cm^2) short pulse ($\approx$ 300 psec) CO_2 laser is used to ionize H_2, Ar, or He gas at pressures high enough to be in a plasma regime rather than a single atom regime. Through X-Ray and forward scattering diagnostics, we have observed a laser-polarization dependent plasma temperature and the generation of both odd and even harmonics which seem to indicate that the plasma is indeed being created by the tunneling ionization mechanism.

1. P. B. Corkum et al., Phys. Rev. Lett. 62, 1259 (1989).

2. F. Brunel, J. Opt. Soc. Am. B. 7, 521 (1990).

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Plasma Physics Aspects of Tunnel-Ionized Plasmas

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The plasma produced by tunneling ionization has, in principle, very well known initial conditions for subsequent laser-plasma interactions. For example, the longitudinal (along $\underline{k}_o$) temperature should be very low making the plasma unstable to the stimulated Raman scattering instability. For a CO_2 laser with linear polarization and a peak intensity of 5×10^{14} W/cm^2, the calculated transverse (longitudinal) electron distribution function resembles a maxwellian with a width of about 50 (< 1) eV while for circular polarization the distribution function should be a " squashed doughnut" with a major radius (transverse to $\underline{k}_o$) of 2.5 KeV and a minor radius of 1 KeV with a longitudinal thickness of only 4 eV. However, time-resolved Thomson scattering measurements from $2k_o$ high frequency instabilities indicate that the plasma conditions may be rapidly evolving on a time scale short compared to the 100 psec rise time of the laser pulse. Instead of the expected narrow-band Raman scattering, broad-band Compton scattering is observed for linear polarization, indicating a high (>100 eV) longitudinal temperature while all high frequency instabilities are suppressed for circular polarization. X-ray measurements confirm that the plasma temperature is high and dependent on laser polarization. In addition, simulation results using the PIC code WAVE which has been modified[1] to include tunneling ionization, will be presented.

1. J. Wallace, Bull. Am. Phys. Soc. 35, 2019 (1990)

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Electrostatic wake-field induced by a short laser-pulse in a plasma

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Following the study presented for the last conference [1], the so-called relativistic regime, associated to a laser irradiance exceeding 10^{18} W/cm^2 (with 1 μm wavelength), has been investigated. The solving of the nonlinear equation for the electrostatic wake-potential [2] has allowed to obtain the various scaling laws for the amplitude and the wavelength of the electrostatic field and also the pulse duration optimum, as a function of the laser irradiance and of the pulse shape. The field steepening has also been quantified and its influence on test-particle acceleration has been obtained. Comparison with 1-D PIC code simulations (EUTERPE) is discussed.

References:

[1] G. Bonnaud, D. Teychenné, J.L. Bobin, 20th Anomalous Absorption Conference, Poster 2P1, Traverse city (Michigan), July 1990

[2] P. Sprangle, E. Esarey, A. Ting, Phys. Rev. A **41**, 4463 (1990)

Multiphoton Ionization Effects in Plasma Waveguides

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Multiphoton ionization of uniform and nonuniform gasses is relevant to nonlinear optics, short pulse (femtosecond) laser development and X-ray laser research. In particular, X-ray laser gain is expected to be significant only for large volumes of high density plasma. We have used a paraxial wave code to study ionization induced refraction and diffraction effects in long scale plasmas. We find that in order to form a large volume of plasma it is necessary to focus laser light onto the tip of a plasma waveguide. Refraction losses at the leading edge of the pulse can lead to a shock-like discontinuity in the laser intensity, whereas dispersion effects at the discontinuity can lead to a significant lengthening of the light pulse.

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X-ray Lasers based on Optical-Field-Induced Ionization

by

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The prospect of continued advances in short-pulse, high intensity, short wavelength lasers makes timely a feasibility study of their potential use as drivers for laboratory soft x-ray lasers. Current x-ray lasers rely on collisionally ionizing a plasma with an optical driver. Recent advances in short-pulse, high intensity laser technology[1] admit the possibility of optically ionizing the plasma to the preferred configuration without excessively heating the ambient electrons. If the post-pulse electron temperature is sufficiently low, a rapid recombination cascade of electrons can occur and lead to significant population inversion. The time-scale for this initial inversion is on the order of a radiative time for transitions to the ground state (3->2 in Li-like or 2->1 in H-like ions), which defines the transient regime of recombination lasing. The conventional recombination laser operates in the quasi-static regime where hydrodynamical effects are critical and the associated laser transitions are between excited states. We concentrate on studying the effects of saturation and parametric heating on energy efficiencies in Li-like Ne in the transient regime. For a 100 fsec, 0.25 μm laser-driver of threshold intensity 10^{17} W/cm^2, an x-ray laser with efficiency 10^{-6} and wavelength 98Å in the transient regime is considered possible. Significant reduction in parametric heating is indicated by merely reducing the laser-driver pulse length to 50 fsec, thereby allowing efficiencies to approach 10^{-4}. We show also that experimentally distinguishing the lasing transition from background spontaneous emission is viable provided the energy efficiency exceeds 10^{-7}. For Li-like Al at 52Å a larger threshold intensity (~10^{18} W/cm^2) necessary for optical-field-induced ionization promotes excessive parametric heating for a 50 fsec driver pulse length and effectively precludes implementation of this scheme over the near term.

[1]M. Pessot, J. Squier, G. Mourou, D. J. Harter, *Opt. Lett.* **14**, 797 (1989); P. Georges, F. Salin, F. Estable, G. Roger, A. Brun, *Ultrafast Phenomena VII*, C.B. Harris, E. P. Ippen, G. A. Mourou, A. H. Zewail, Eds. (Springer-Verlag, Berlin, 1990), pp. 48-50; F.G. Patterson, M.D. Perry, R. Gonzales, and E.M. Campbell, In *Femtosecond to Nanosecond High-Intensity Lasers and Applications*, E. M. Campbell, Ed. (SPIE, Bellingham, 1990), pp. 2-18; D. J. Harter, M. Pessott, J.A. Squier, J. Nees, P. Bado, G.A. Mourou, *ibid*, pp. 19-28; W. Tighe, C.H. Nam, J. Goldhar, L. Meixler, J. Robinson, E. Valeo, and S. Suckewer, *ibid*, pp. 29-39; H. C. Kapteyn, A. Sullivan, H. Hamster, R. W. Falcone, *ibid*, pp. 75-81.

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Enhanced Absorption of Electromagnetic Radiation in Plasmas Due to Correlated Collisions

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Recent experiments by Leemans et al. indicate anomalously fast nonlinear plasma heating by laser irradiation. To explain these results we have developed a model which predicts an enhancement in the electron-ion collision frequency. When the excursion amplitude λ_{osc} of a plasma electron quivering in the laser field exceeds the Debye length λ_D and when the collision frequency $\nu << \omega\lambda_D/\lambda_{osc}$, then the electrons which are suffering small angle collisions with the ions will necessarily re-encounter the same ion in the same orientation on their next quiver oscillation. These subsequent collisions with the same ions are not random as is usually assumed in collision models but are correlated to the previous collisions. Including the effect of correlated collisions this enhances the electron-ion collision frequency by a factor of (ω/ω_p). This simple physical model is compared to the results of the Dawson-Oberman model for anomalous resistance and to PIC simulations.

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21th Anomalous Absorption Conference, Banff, Canada, 1991

Resonant Absorption in a Parabolic Density Profile

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Resonant absorption of an electromagnetic wave in an inhomogeneous plasma is relevant to the physics of laser matter interaction and ionospheric heating experiments. This wave conversion is studied experimentaly near the top of a parabolic density profile where the convection speed of the electron plasma wave is much lower than in a steep profile. Zakharov equations are used to model the E.P.W propagation and coupling with ion acoustic waves.

The experiment ($n = 10^{11} cm^{-3}$, $V \sim 0,8\ m^3$, $Te \sim 3eV$) shows the build up of a large density cavity - 1000 λ_d - where the EPW are trapped. A relaxation mechanism takes place. Plasma is expelled out of resonant region and electron density, on the border of the cavity, can exceed the critical one; the cavity is then decoupled from the E.M. field, the EPW decays, the density gets subcritical. The cavity is again pumped by the E.M field.

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ABSTRACT

Theory of Stimulated Brillouin Scattering in time-dependent, inhomogeneous media

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Stimulated Brillouin scattering (SBS) has long been recognized as an important laser-plasma instability. It can occur in principle at any density up to the critical density of the irradiating laser, and has been observed in some cases to be very efficient. The linear theory of this instability should be useful in helping to identify thresholds, gains, conditions for absolute instability, and possible control strategies. However, such theory to date has been developed entirely for time-independent media, while in experimental plasmas both the flow velocity and the expansion velocity of the medium are often comparable to the group velocity of the ion sound wave driven by SBS. In this paper we discuss the methodology required to evaluate the gain in such cases and we consider SBS in three cases of interest: (1) large, time-dependent plasmas like those produced by exploding foils, (2) planar, isothermal rarefactions like those produced by irradiating large areas on thick targets, and (3) subsonic, time-independent rarefactions similar to those produced by irradiating small areas with short-wavelength or low-intensity light.

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Stimulated Brillouin Backscattering in Large, Underdense Laser Plasmas

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Stimulated Brillouin scattering (SBS) is an important process for laser-fusion targets but remains incompletely understood. Interpretation of many past experiments is complicated either by the presence of critical and quarter-critical density surfaces or by strongly driving the instability in low-temperature plasmas. We have recently conducted experiments which avoid these complications.

The plasma parameters are chosen to be relevant to proposed high gain schemes. Large (L ≈2-3 mm) underdense plasmas ($n_e/n_c \leq 5\%$) are formed by illuminating CH foils with 0.351 μm light. Following formation, the instability is driven with one 0.531 μm beam and the directly backscattered light is both spatially and temporally resolved. The absolute reflectivity is also measured. Results of the experiments are compared to linear theory and future experiments are discussed.

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STIMULATED BRILLOUIN SCATTERING DRIVEN BY 10 PS LASER PULSES

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Recent measurements[1] of stimulated Brillouin scattering (SBS) from 10 ps experiment are compared with the results of analytical and numerical calculations. The linear growth of the instability from the thermal noise is investigated by means of analytical theory, which accounts for the initial pulse propagation through the preformed plasma. The pump depletion and ion wave nonlinearities are included in the numerical model based on the set of Korteweg - de Vries/Maxwell equations. In case of long plasmas (L > 1mm) the sound waves display nonlinear features such as harmonic generation, even for moderate laser intensities ($I > 5x10^{14}$ W/cm^2). Analytical calculations of reflectivity are compared with numerical and experimental results.

1. H. A. Baldis, H. C. Barr, D. M. Villeneuve, G. D. Enright, B. La Fontaine, J. E. Bernard, Proc. SPIE Int. Soc. Opt. Eng. **1229**, 144(1990).

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INTERACTION BETWEEN STIMULATED BRILLOUIN SCATTERING AND FILAMENTATION INSTABILITY IN PLASMAS.

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The set of equations describing Stimulated Brillouin Scattering (SBS) and the Filamentation Instability (FI) are solved numerically for a spatially periodic system. For *short* systems (a few wavelength of the incident light) SBS backscatter modes and the filamentation instability are observed as we expect but in addition there are some puzzling features. SBS starts after a time delay, is localized, and focuses during its evolution. These features disappear for a *long* (tens of the wavelength) system for which sidescatter modes are dominant. The energy is dispersed among many non coherent modes in such a system and none of the modes is strong enough to drive filamentation. The analytic explanation of the 'puzzling features' is given. Some results of simulations with nonperiodic boundary conditions are also presented.

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THREE-DIMENSIONAL SIMULATIONS OF FILAMENTATION*

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We have constructed a 3-D time-dependent beam propagation code in Cartesian geometry to study filamentation of the incident laser light in underdense plasmas. This code will be used to guide and interpret the planned NOVA experiments on beam smoothing. We will discuss results on ponderomotive and thermal filamentation for parameters of current interest. Our models show that the 100 ps experiment of P. Young et al.[1] is not in steady state.

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

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

ORAL SESSION 3

J. Meyer, Chair

PLASMA INTERACTIONS I

21st Annual Anomalous Absorption Conference
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NONLINEAR INTERACTION PROCESSES IN LONG-SCALE-LENGTH PLASMA EXPERIMENTS ON OMEGA

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The present series of long-scale-length interaction experiments on OMEGA is based on the multiple-beam irradiation of flat targets, in order to create ~ 0.5 mm density scale lengths at $n_e \leq n_c/4$ with electron temperatures above 1 keV. Due to the design of the experiments the decrease in density during the expansion phase is slowed down near the center of the target while the density goes from quarter critical to tenth critical. The experiments have been carried out with distributed (random) phase plates (DPP's) in the beam in order to improve the average illumination uniformity. In addition, smoothing by spectral dispersion (SSD) has also been applied; these experiments increase the illumination uniformity by combining the effects of the DPP's with those of the FM bandwidth on the laser beam.

The nonlinear interaction of primary interest was the stimulated Raman scattering instability. The observed threshold for this instability of ~ 2×10^{14} W/cm^2 agrees very well with that predicted[1] on the basis of strong collisional damping of the electron plasma waves, as is appropriate for the plasma conditions in this experiment. Saturation of the SRS signals is observed near 10^{15} W/cm^2. While the limited bandwidth of ~ 5 cm^{-1} (at 351 nm) would not be expected to influence the SRS instability directly, a significant reduction of the SRS saturation levels has been observed, together with a significant increase in the SRS threshold intensity in the presence of bandwidth.

Brillouin scattering was investigated in the backscatter and sidescatter directions. The spectral signatures and their dependence on the irradiation conditions appear to indicate an absence of significant ion-acoustic wave intensities. There is no observable threshold, and the red-shifted spectral line typically associated with Brillouin scattering is not seen. Evidence of filamentation has been found in schlieren photography under conditions favorable to filamentation.

[1] E.A. Williams, LLNL 1985 Annual Report, pp. 2-46 to 2-50.

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THE FILAMENTATION INSTABILITY IN THE PRESENCE OF MORE THAN ONE PUMP WAVE

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The filamentation instability is of particular interest for direct-drive laser fusion because of its potential consequences for laser light absorption and drive uniformity. The linear growth of the instability is well understood in the case where a single laser pump wave propagates through a homogeneous plasma. In direct-drive geometries, however, several laser beams illuminate each region of the target, and in recent beam-smoothing schemes such as SSD and ISI each beam is itself subdivided into many smaller beamlets. Langdon[1] has shown that in general the presence of light propagating obliquely to a filament tends to suppress the instability, but it is not clear how large the angle of propagation with respect to the filament must be to achieve this effect. To explore this question we consider the filamentation instability in the presence of two pump waves propagating at an arbitrary angle to each other. The thresholds and growth rates are determined as a function of this angle, and the consequences for filamentation in multiple-beam illumination geometries discussed.

[1]LLNL Annual Report 1983, p. 3-35.

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FOKKER-PLANCK SIMULATIONS OF LASER FILAMENTATION IN PLASMAS

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The effects of nonlocal electron heat transport on the nonlinear evolution of both thermal and ponderomotive laser filamentation has been modeled using the Fokker-Planck (FP) code SPARK. The code solves the FP equation for the electrons, the full hydrodynamic equations for the ions, and the paraxial wave equation for the laser light, in Cartesian geometry. Filamentation simulations, under the experimental conditions reported by Young et al. [Phys. Rev. Lett. **61**, 2336 (1988)], confirm the recent predictions based on analytic theory [E. M. Epperlein, Phys. Rev. Lett. 65, 2145 (1990)] that the kinetic thermal mechanism dominates over the ponderomotive mechanism.

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DYNAMICS OF HOT SPOT FILAMENTATION

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It is well known that ponderomotive filaments cannot form with power less than a certain critical amount, Pc, which varies linearly with the electron temperature, and inversely with the plasma density. In the dynamical regime determined by ion inertia, it is also known that dynamically collapsing filaments can be found if the total power, P > Pc.

When the laser beam is diffraction limited, as in a hot spot, these ponderomotively collapsing filaments form a one parameter family indexed by P. For given P, all collapsing filaments are identical except for simple scaling of collapse time with beam intensity and collapse depth with beam radius. If P $\gg$ Pc, the dependence upon P drops out.

If the beam radius is large compared to an electron mean free path, then the initial stages of collapse are thermally dominated. For time scales less than a thermal diffusion time and less than an ion acoustic transit time across the beam, a family of thermally driven collapsing filaments is obtained, which are simply related to one another through simple scaling relations.

At the end of such collapses, all but an amount of power of order Pc, escapes from the end of the filament. The "end" of the filament, which corresponds to a dynamic focal point, at first moves supersonically towards the laser [1-3]. This diffractive burst of radiation and the dynamic focus may be experimentally observable.

[1] A. G. Litvak, V. A. Mironov and A. M. Sergeev, Physical Scripta, vol. T30, page 57 (1990).
[2] H. A. Rose, D. F. DuBois and D. Russell, in volume 2 of Nonlinear World, page 955, (edited by V. G. Bar'yakhtar et al., World Scientific, 1990).
[3] H. A. Rose, D. F. DuBois and D. Russell, Fizika Plazmy, vol. 16, page 926, (1990). English language version available in Soviet Journal of Plasma Physics and Los Alamos Report LA-UR-3349.

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The Effect of Bandwidth and Induced Spatial Incoherence on the Convective Raman Instability

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The effect of bandwidth on the convective amplification of the Raman instability in the underdense, inhomogeneous plasma is investigated. For the case when the homogeneous growth rate $\gamma_0 \ll \Delta\omega$, the bandwidth, it is shown both analytically and numerically that there is no effect of bandwidth on the convective amplification. The reduction in the homogeneous growth rate due to the bandwidth is compensated for by an increase in the interaction region such that the convective amplification is unaffected. This is true as long as the interaction length is larger than the plasma size a condition that is readily met for all present day experiments with bandwidth. For $\gamma_0 \gtrsim \Delta\omega$ there is a statistical enhancement in the amplification factor.

The role of induced spatial incoherence on the convective amplification has been studied numerically. For bandwidths comparable or larger than the time averaged growth rates the spatial smoothening of the laser light intensity leads to reduced convective amplification. On the other hand for smaller bandwidths there is statistically enhanced convective amplification because of the absence of beam smoothening.

Abstract submitted to the 21st Annual Anomalous Absorption Conference

Saturation of Stimulated Raman Forward Scattering: Possible Causes

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A recent experiment has shown that the stimulated Raman forward scattering (SRFS) instability in millimeter-sized plasmas can be easily saturated.[1] Usually, saturation is ascribed to a nonlinear plasma response to the instability. However, the geometry of this experiment suggests that the finite extent of the plasma may cause saturation before nonlinear effects become important.

In the experiment, the plasma was preformed using 15 kJ of 351 nm light and a thin CH foil. The resulting plasma had an electron density which was parabolic along the target normal. Significant deviations from planarity occurred away from the target normal. The SRFS instability was driven by a high-intensity, 527 nm interaction beam which struck the target at 50° to the target normal.

The hypothesis that the instability remains linear will be tested in two ways. First, the predicted scattered-light spectrum, including scattering produced far from the peak electron density, will be calculated and compared to preliminary measurements. Second, the SRFS gain factor will be determined by numerically integrating through the plasma, taking explicit account of the curvature and variation of the density gradient, as well as laser-beam inhomogeneities.

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1 S. H. Batha *et al.*, Bull. Am. Phys. Soc. 35, 1943 (1990).

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RAMAN CONVECTIVE GAIN FOR PLASMAS WITH HOT ELECTRON POPULATIONS

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The near universal lack of agreement between observed Raman characteristics and predictions of threshold and spectral range based on conventional theory has led to a reappraisal of this theory on the one hand and on the other to an interpretation in terms of enhanced Thomson scattering driven by a flux of hot electrons .

Past attempts to examine stimulated Raman scattering from a plasma with a suprathermal electron component using a PIC code gave results that were in some aspects at least, equivocal. The picture that emerged from earlier work by Boyd, Coutts and Gardner showed a complicated picture of the influence of the flux of hot electrons on the Raman spectrum, with a sensitive dependence on the ratio of the temperatures of the hot and cold electrons. In the results to be presented we have used a fluid code to re-examine the Raman gain in the presence of a population of hot electrons.

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Beat-Wave Experiment at Ecole Polytechnique

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The beating of two laser beams in a plasma can generate a large amplitude plasma wave which is resonantly excited. Various saturation and detuning mechanisms of the beat plasma wave can be involved such as modulational instability, collisional effects, plasma expansion, ...

We present a theoretical analysis and experimental results obtained in a beat wave experiment performed with both Nd-YAG and Nd-YLF laser wavelengths in a H_2 or D_2 plasma.

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Spatiotemporal Dynamics in the Nonlinear Three Wave Interaction

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Abstract

The nonlinear three wave interaction describes many phenomena in plasma physics, nonlinear optics and hydrodynamics [1]. The equations describe the nonlinear evolution of three interacting wave packets. For non-dissipative/non-growing wavepackets the space-time evolution of their nonlinear interactions can be solved by inverse scattering transforms; soliton solutions are found. With dissipation and/or growth we can expect spatiotemporal quasiperiodicity and chaos. We have examined two non-conservative models that are relevent to laser-plasma interactions.

The first model involves SBS in a finite region. We consider a pump laser impinging on the medium exciting a Stokes mode and a heavily damped (spatially) acoustic mode. This model is applicable to SBS in optical fibers and large-scale laser plasmas. With a constant noise source seeding the interaction we find that the interaction relaxes to a steady state. However if a small amount of dephasing is included we see transitions to quasiperiodicity and chaos. For a randomly fluctuating noise source we observe significant fluctuations in the the transmitted pump and Stokes waves.

The second model involves the saturation of a linearly unstable parent wave by coupling to two damped daughter waves. For the parent wave having the middle group velocity we observe spatiotemporal chaos involving the chaotic dynamics of coherent structures. We also consider the case where the parent wave has the highest group velocity. This could correspond to a pumped (as in SRS) electron plasma wave decaying to another plasma wave and to an ion acoustic wave.

This work was supported in part by LLNL subcontract B108475, DOE contract no. DE-AC02-78ET-51013 and NSF Grant No. ECS-88-2475.

[1] D. Kaup, A. Reiman, and A. Bers, Rev. Mod. Phys. **51**, 915 (1979).

INVESTIGATION OF THE RELATION BETWEEN TWO PLASMON DECAY AND STIMULATED BRILLOUIN SCATTERING AND ITS IMPACT ON (3/2) HARMONIC EMISSION

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Electron plasma waves generated by the Two Plasmon Decay and ion acoustic waves generated by the Stimulated Brillouin Scattering instabilities in an underdense CO_2-laser produced plasma are studied by ps-resolution Thomson scattering of probe ruby laser light. Both the spatial and the wave vector distributions over a wide k-range of the unstable, saturated waves are observed. The results indicate a close interaction between both instabilities which can be explained by a simple coupling model. It is shown that this model can explain features of the observed angular distribution of (3/2) harmonic emission. The analysis leads to a new interpretation of (3/2) harmonic spectra allowing temperature measurements of laser target coronas.

TEMPERATURE ISSUES IN LASER TARGET CORONAS

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A coupling model of Two Plasmon Decay (TPD) and Stimulated Brillouin Scattering (SBS) is used to analyse (3/2) harmonic spectra published by various international laboratories. The model predicts the wave vectors of the dominant TPD decay plasmons which, after propagation up or down the density gradient lead to $(3/2)\omega_0$ emission. The harmonics spectra can then be used to determine the corona temperature. All measured temperatures are consistent and show the following trends. They increase with target z, are higher for exploding foil than for disk targets and show little dependence on laser wavelength. These temperatures are in general agreement with those derived from code calculations. However they are higher than predicted by Landau damping considerations which can be derived from Stimulated Raman Scattering spectra and angular (3/2) harmonic intensity distributions. The discrepancy may indicate that the electron distribution bulk temperature is higher than its tail temperature in target coronas.

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TRANSIENT EFFECTS IN PARAMETRIC INSTABILITY GROWTH*

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If there is insufficient time for one or both of a pair of parametrically coupled waves to cross the coupling region, determined by the presence of the pump, or by plasma inhomogeneity, the instability fails to attain its time-asymptotic state. Absolute instabilities such as SBS backscatter grow faster than predicted by time-asymptotic theory, and effective thresholds are lower.

We show results on both convective and absolute instabilities in both one and three dimensions.

These results are of interest in current experiments using short pump pulses irradiating preformed plasmas.

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

BANQUET

Reception - Max Bell Foyer	6:30 - 7:00 p.m.
Dinner - Dining Hall	7:00 - 8:00 p.m.

GUEST SPEAKER:

Dr. E.W. Vogt, Director of Triumf

TOWARD THE HEART OF MATTER

BUSINESS MEETING

C.E. Capjack, Chair

ORAL SESSION 4

G.D. Enright, Chair

X-RAY DIAGNOSTICS AND X-RAY LASER

Designs for Coherent Soft X-Ray Lasers*

R. A. London
University of California, Lawrence Livermore National Laboratory
Livermore, CA 94550

The property of coherence is important for applications of x-ray lasers such as holography of biological cells. The longitudinal coherence of current x-ray lasers should be sufficient, but the transverse coherence needs improvement.

We describe several recently developed methods to model the buildup of transverse coherence in x-ray lasers, including such effects as gain and refractive index variation. These methods are based on the paraxial wave equation, including a spontaneous emission source term. The observables of the laser (the intensity and coherence) are given by the mutual coherence function – the ensemble averaged electric field complex product. We present results of these models for the expected coherence of current x-ray laser configurations and describe the status of recent experiments to measure the transverse coherence.

Several methods for improving the transverse coherence are suggested. Increasing the amplification factor, through the gain-length product, is the most direct way to increase the coherent energy output. This must be achieved without saturating the gain with unwanted modes.

The first method is to utilize the gain guiding and refractive defocusing inherent in a exploding foil laser to improve coherence. These effects act as a distributed spatial filter to eliminate unwanted modes.

The second method is to use a normal incidence mirror to create a second pass, thereby achieve higher gain-length. Several possible forms of spatial filtering involving distant placement of the mirror, pinholes, and convex mirrors will improve the coherence and avoid saturation with unwanted modes.

The third method is to use an oscillator-amplifier architecture similar to those used in high power optical lasers. The first stage would, by virtue of it small cross-section and spatial filtering, produce a coherent x-ray output. These x rays would be injected into a second stage designed as an amplifier.

Detailed designs of several x-ray laser configurations and experiments to characterize the physics needed for these designs and to measure the power output, angular beam pattern and coherence of these lasers are described.

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

Designs for Nickel-like Soft X-Ray Lasers Using Fast Pump Lasers (20<100ps)*

S. Maxon
Lawrence Livermore National Laboratory
Livermore, CA 94550

Designs for Nickel-like Ta soft x-ray lasers have been investigated for pump lasers in the range 20-100ps. Although high gains can be achieved, refraction is a problem.

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

A Search for 2p-2s Gain in a Collisionally Excited Ge Plasma

Gerry
G.D. Enright, H.A. Baldis, J. Dunn, B. La Fontaine, D.M. Villeneuve
National Research Council of Canada
J.C. Kieffer and H. Pépin
INRS-Énergie

Soft x-ray amplification in collisionally excited Ne-like Ge plasmas has been extensively studied. Gains in excess of 4 cm^{-1} have been reported for the 3p-3s transitions. The present experiments make use of a novel focusing arrangement that produces a highly uniform linear plasma. With this arrangement gain was observed on a core-excited $2s2p^6 3d$-$2s2p^6 3p$ J=2-1 transition at 199 Å. These measurements have been extended into the 60-90 Å region where inversion on 2p-2s core-excited transitions is expected. These lines would appear among the Ne-like satellites of the F-like resonance lines at 65.90 and 79.75 Å. Likely candidates are of the form $2s2p^6 3d$-$2s^2 2p^5 3d$ at 80.9 Å (J=2-1), 64.9 Å (J=1-1), 85.3 Å (J=2-1), and 85.6 Å (J=1-1) and $2s2p^6 3s$-$2s^2 2p^5 3s$ at 63.1 Å (J=0-1), 75.1 Å (J=0-1), and 79.1 Å (J=1-1). The wavelengths have been determined from calculations that take into account the measured 3-3 wavelengths and the L-shell emission wavelengths. Observation of gain on these transitions would be significant as it would allow scaling of Ne-like lasers to shorter wavelengths.

Uniformity Issues in X-ray Laser Line Focii

D. M. Villeneuve, H. A. Baldis, J. Dunn,
G. D. Enright and B. La Fontaine

National Research Council of Canada
Ottawa Canada

J-C Kieffer, M. Nantel, M. Chaker and H. Pépin

INRS-Energie
Varennes, Québec

The illumination uniformity along the laser line focus is important for producing a uniform linear plasma for x-ray laser studies. We will describe optical and x-ray diagnostic techniques used to assess the density and temperature uniformity of long plasmas. A beam smoothing technique (a segmented wedge array) was used to improve the laser uniformity. Advantages and disadvantages of this technique will be discussed.

Plasma Characterization of X-ray Lasers

B. La Fontaine†, H.A. Baldis, J. Dunn, D.M. Villeneuve,
G.D. Enright, H. Pépin†

National Research Council of Canada

M.D. Rosen, D.L. Matthews

Lawrence Livermore National Laboratory

The understanding of the gain medium in x-ray lasers is of great importance, but it is still inadequate. In that respect, a precise characterization of the plasma can aid in the optimization of the conditions for lasing. We report characterization measurements of plasmas relevant to x-ray lasers, using thermal Thomson scattering techniques to obtain the electron and ion temperatures (T_e and T_i), as well as drift velocities. Interferometry with a 10 ps, 355 nm probe beam was used to measure the electron density profiles.

The *LP2* laser system was used to produce the plasma, using 2 ns pulses at 1.064 µm and with energies up to 200 J. A parametric study was done where the irradiance varied from 10^{13} W/cm^2 to 10^{15} W/cm^2, and where different materials (Z = 6,13,32,72) were used as targets. A mapping of the parameters' spatial variation was also performed in spherical and line focus geometries. The measured temperatures are compared to values obtained from the continuum and line emission in x-ray spectra, as well as to hydrodynamic computer modelling.

* *Part of 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.*

† *Permanent address : INRS-Énergie, C.P.1020, Varennes, Québec, J3X 1S2*

Model Calculations for Soft X-Ray Lasers in Nickel-like Ions*

A.L. Osterheld, R.S. Walling, W. H. Goldstein,
J.H. Scofield, M.H. Chen, B.J. MacGowan, S. Maxon
Lawrence Livermore National Laboratory.

We have developed a collisional-radiative model to describe the kinetics of nickel-like ions. The model consists of relativistic fine structure levels for iron-like through copper-like ions imbedded in a configuration average model. Careful attention has been paid to auger processes such as dielectronic recombination, and excitation-autoionization. We will present results from calculations of the ionization balance of the plasma, and will describe the relative importance of different excitation mechanisms for producing gains on n=4-4 nickel-like and cobalt-like lasing transitions.

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

Ionization Balance in Photoionized Plasmas*

R. S. Walling, A. L. Osterheld, M. R. Carter, R. E. Stewart, W. H. Goldstein, J. H. Scofield, P. B. Duffy, and H. A. Scott

Lawrence Livermore National Laboratory
Livermore, CA 94550

Upcoming experiments at the Livermore Nova Two-Beam Facility will measure the ionization balance in photoionized gas targets using irradiation from a laser-heated high-Z converter target. In a photoionized plasma, the contribution to ionization by electron-impact collisions is minimal. Therefore the electron-impact processes only affect the total recombination rates in the plasma through the specific processes of three-body recombination, radiative recombination, and dielectronic recombination. Each of these three recombination processes can dominate in a particular range of plasma electron temperature and density. We can easily minimize three-body recombination by operating at lower gas pressures. Although potentially harder to achieve in practice, differentiating between radiative recombination and dielectronic recombination can be brought about by heating the gas sample to different electron temperatures. For example, radiative recombination dominates at low T_e. Currently we are modeling the atomic physics and hydrodynamics of specific argon and krypton gas targets driven by filtered x-ray sources to find the range of parameter space (n_e and T_e) and recombination regimes we can reach in these experiments.

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

<u>Detailed Spectroscopy Postprocessor for H-, He-, and Li-like Ions.</u>* C.J. Keane, R.W. Lee, and J.P. Grandy, Lawrence Livermore National Laboratory, Livermore, CA 94550- A postprocessor code suitable for use with LASNEX or other hydrodynamic code output has been developed. The program will generate detailed H-, He-, and Li-like spectra for 6≤Z≤26 given standard hydrodynamic output quantities (density, temperature, and the like). For a given hydrodynamic calculation, the rate equations are integrated in time or solved in steady state to give the ionization balance and excited level populations as a function of time and zone. These quantities are then used to construct emissivities and opacities as a function of energy; the equation of radiative transfer is then solved to yield an output spectrum. Detailed lineshapes including both Doppler and pressure broadening effects are included. The bulk of the physics routines for the kinetics and lineshape generation have been drawn from the steady state POPULATE/SPECTRA spectral generation package. Further details regarding the program and examples of its use will be given.

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

Monte Carlo simulation of complex spectra for opacity calculations*

P. Duffy *(Lawrence Livermore Laboratory),* M. Klapisch** *(Lawrence Berkeley Laboratory),* J. Bauche and C. Bauche-Arnoult, *(Laboratoire Aime Cotton, Univeriste Paris Sud)*

Although exact calculations of complex atomic spectra and their opacities are not hard in principle, the number of lines involved makes this time-consuming and often impractical. We have therefore developed a new, Monte Carlo technique for modelling spectra with many resolved lines. It is based on previously known statistical properties of transition arrays and is intended mainly to calculate opacities.

Our approach is based on the idea that wavelength-averaged opacities do not depend much on the strengths or positions of individual lines in a complex spectrum. That is, if there are enough lines in the spectrum, calculated opacities will be approximately right as long as certain *statistical* properties of the spectrum are correct. Thus we avoid calculating line strengths and energies explicitly and instead choose them randomly from assumed statistical distributions; this makes the model very fast. The forms and parameters of these distributions are obtained through a combination of theoretical and empirical means.

We demonstrate the feasibility of the technique for cases near LS-coupling by showing that for a simple spectrum of iron it gives

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* Work performed under auspices of the U. S. Dept. of Energy by the Lawrence Livermore National Laboratory under contract no. W-7405-Eng-48

** On leave from Hebrew University, Jerusalem, Israel

21^{st} Annual Anomalous Absorption Conference
Banff, Alberta, Canada
April 14-19, 1991

SIMULATION OF ABSORPTION SPECTRA FROM HIGH-DENSITY IMPLOSIONS OF ARGON FILLED POLYMER SHELL TARGETS

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Rochester, New York 14623

R. C. Mancini and C. F. Hooper
DEPARTMENT OF PHYSICS
University of Florida
Gainesville, FL 32611

We present results of simulations of experiments in which polystyrene (CH) shells. filled with argon gas were imploded with the 24-beam UV (351-nm) OMEGA laser. The one-dimensional hydrodynamic code LILAC, which includes an average-ion model, is used to compute the conditions in the core. Spectra are calculated from these results using a postprocessor that calculates the atomic physics and radiative transport in terms of a non-LTE multi-species detailed-configuration atomic model. Density-dependent Stark-broadened absorption line profiles for each species are included. The predicted species populations and spectra indicate that density-broadened argon lines are emitted before shock reflection from the target center. Simulations indicate that during the reflection of the compression shock back to the shell, the emission from the dense hot center part of the core ($n_e < 10^{25}$ cm^{-3}) will be absorbed by the species present in the cooler and less dense outer part of the core ($n_e < 5 \times 10^{24}$ cm^{-3}). Simulation results are compared with experimental measurements. The implications of these results for applying absorption spectroscopy to diagnosing high-compression fusion experiments will be considered.

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

21st Annual Anomalous Absorption Conference
Banff, Alberta, Canada
April 14-19, 1991

SPACE-RESOLVED SPECTROSCOPY OF OMEGA CD TARGET IMPLOSIONS

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We have obtained spectrally dispersed x-ray images of evacuated deuterated polystyrene (CD) shell targets imploded by the OMEGA laser system. Up to 1.4 kJ of UV (351 nm) light in 650 ps (FWHM) pulses were used to implode the targets, which were ~ 250 μm in diameter and 10 to 14 μm thick. The x-ray images were obtained with a Kirkpatrick-Baez (KB) microscope having gold-coated reflecting surfaces that permit sensitive imaging of x rays up to ~ 7 keV with a resolution of ~ 5 μm. A gold transmission grating with an 0.2 μm period was placed in the microscope to disperse the x rays according to wavelength. The images were recorded with DEF film.

We present x-ray spectra of the implosion stagnation regions for a series of CD target experiments obtained with this spectrally dispersed KB microscope. The observed spectra show continuum emission from the hot CD plasma (kT ~ 1 keV) at the center of the shell stagnation (core). Estimates of the electron temperature of the core emission can be inferred from the high energy portion of the spectrum. The lower energy x-rays ($E \lesssim 4$ keV), emitted from the core, are predicted to be absorbed by the surrounding colder plasma. We show how estimates of the ρR can be inferred from the observed spectra.

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

REVIEW TALK 4

R.A. London, Chair

X-RAY LASERS - PROGRESS AND PROSPECTS

M.H. Key

MIXED POSTER SESSION 4

Pulse Shaped Indirectly Driven Implosion Experiments*, D. R. Kania, S. M. Lane, R. E. Turner, S. Hatchett, S. Haan, R. Thiessen, and L. Suter, *Lawrence Livermore National Laboratory, L-473, Livermore, CA 94550*. We have performed a series of indirectly driven implosion experiments using shaped laser pulses that have achieved a $\rho R_{fuel} > 26$ mg/cm^2. The Nova laser was used to generate a 27 kJ of 0.35 μm light in a 11 to 1 contrast pulse that was 3.2 ns long. The laser light was used to heat a millimeter scale gold hohlraum. The capsule was constructed of glass and plastic and contained DT fuel. The drive symmetry was measured with an independent set of experiments using gated x-ray imaging of DD filled plastic capsules. The typical target yield (DT) was 2×10^{10} neutrons. The ρR_{fuel} was inferred from a measurement of the ρR_{pusher} using neutron activation of Rb dopant in the pusher. The inferred $n\tau$ for these targets is 4×10^{14} s/cm^3.

*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.

4P2

Characterization of Laser-Driven Burn-Through Foils for Radiatively Heated Plasma Experiments*, D. R. Kania, B. A. Hammel, R. W. Lee, M. J. Edwards†, P. E. Young, H. N. Kornblum, S. G. Glendinning, S. Dixit, M. Henesian, and H. T. Powell, *Lawrence Livermore National Laboratory, L-473, Livermore, CA 94550.* We have investigated the characteristics of a laser-irradiated burn-through foil as an x-ray heating source for opacity and equation of state experiments. This radiation source has the advantage of permitting the sample to be isolated from direct laser light and plasma from the radiation source. One arm of the Nova laser is used to generate approximately 3 kJ of 0.53 μm light in a 1 ns pulse. The f/4 focussing optic includes a 74 cm diameter phase plate with a 3 mm effective beamlet size. The beam line includes a 3 x 3 array of optical wedges to generate a flat topped intensity distribution of 10^{14} W/cm^2 in the target plane. The burn through foils are typically 2500 Å thick, free standing foils of gold. The time evolution of the absolute and relative soft x-ray emission from the foil was measured with an x-ray diode array and streaked, variable spaced grating (VUV) spectrograph. X-ray images of the source were taken with time resolved and static x-ray pinhole cameras. The amount of transmitted laser radiation was measured with an opposed port calorimeter and optical imaging system. Preliminary results indicate that a significant fraction of the incident laser light is converted to x-rays on the backside of the target with very little laser light transmitted to the sample position.

†Permanent address Imperial College of Science and Technology, London, UK.

*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.

Absorption Measurements of X-ray Heated Low-Z Materials*, B. A. Hammel, D. R. Kania, R. Doyas, R. W. Lee, and C. A. Iglesias, *Lawrence Livermore National Laboratory, L-473, Livermore, CA 94550*, J. F. Seely, U. Feldman and C. M. Brown, *Naval Research Laboratory, Washington, DC 20375*. We are studying the opacity of radiatively heated low-Z samples (Z=5-7) in the spectral region of their K-edges (~250-500 eV), with the eventual goal of investigating radiative transfer in non-LTE plasmas. In these experiments one arm of the Nova laser (4 kJ of 0.53 μm light in a 1-ns pulse) is incident on a Au burn-thru foil (0.25 μm thick), producing a soft x-ray source that radiatively heats a low-Z sample. The sample is ~1-μm thick and is placed in close proximity (~2 mm) to the Au foil. Absorption spectra are obtained by either viewing the soft x rays from the Au foil passing thru the sample, or by using a second arm of the Nova laser to create an independent xray backlighter pulse from a separate Au foil at a specific time. High resolution, spectral measurements ($\lambda/\Delta\lambda > 3000$) are obtained with a 3-m Rowland circle instrument and data are recorded on photographic plates (Kodak 101-05). Preliminary comparisons with a low-Z opacity code, OPAL, are 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 21th Annual Anomalous Absorption Conference

ARC SOURCES FOR HEAVY ION FUSION DRIVERS*

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Proposed accelerators for Heavy Ion inertial confinement Fusion (HIF) have stringent requirements on ion beam quality so that the necessary energy can be tightly focused on the target. A crucial beam parameter that affects focusability, the normalized emittance ϵ_n, is related to the transverse temperature $T_\perp$ and must be suitably small to allow small focal spots. ϵ_n can only increase in the HIF scheme using induction accelerators and thus can be no smaller than the level delivered by the source–adding another constraint to the source requirements. The ion source must provide a high flux of the desired ion at low temperature with the proper charge state. The source must prevent these ions from entering the accelerator until the beginning of the beam pulse and, thereafter, supply enough ions to meet the current requirements until the end of that pulse. ϵ_n from the source should be as small as possible to provide maximum freedom in subsequent beam manipulations. The arc-generated plasma source at LBL easily satisfies the ion flux requirements but encounters difficulties in achieving the ϵ_n desired. We have found the predominate source of ϵ_n is not due to the intrinsic temperature of the arc but rather due to the ion interaction with the "switch" mesh. We have proposed techniques that should reduce these interactions that are now being investigated experimentally.

† Lawrence Berkeley Laboratory, Berkeley, CA 94720

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

מדינת ישראל
GOVERNMENT OF ISRAEL

SOREQ NUCLEAR RESEARCH CENTER
ISRAEL ATOMIC ENERGY COMMISSION

המרכז למחקר גרעיני נחל־שורק
הועדה לאנרגיה אטומית

POPULATION INVERSION IN A MUON CATALYZED FUSION MEDIUM AND THE POSSIBILITY OF X-RAY LASING.

Z. Henis and S. Eliezer

Plasma Physics Department

Soreq Nuclear Research Center, Yavne 70600, Israel

It is suggested that a population inversion of the levels of dμ atoms occurs in a muon irradiated deuterium - tritium mixture. The measurement of the transition n=3 to n=2 (370 eV photons) can shed light on the Q_{1s} (the ground state population of dμ atoms) problem. The possibility of creating an X-ray laser with photon energy of 370 eV during muon cascade is discussed.

The effects of Non-uniform Laser Beams on Conversion Efficiency

Steven H. Langer
Lawrence Livermore National Laboratory[1]

Most models of the conversion efficiency of a gold disk assume that the laser intensity is uniform across the laser spot. This is a poor representation of a real laser beam, which often has regions where the intensity is many times higher than the mean intensity. These laser non-uniformities are a very serious problem for direct drive ICF target performance, because drive asymmetries will imprint themselves on the target and reduce the yield due to mix and asymmetric fuel configurations. Non-uniform laser drive is also a problem for indirect drive targets, even though the x-rays falling on the target are much smoother than the laser beam.

The goal of this paper is to quantify the relationship between the smoothness of an incident laser beam and the x-rays emitted by a gold disk. LASNEX will be used to model a laser beam with a sinusoidal intensity modulation in the transverse direction. The degree of smoothing of the x-rays as a function of the distance scale of the perturbation and the length of time the perturbation has been applied will be discussed. Some preliminary results on the relationship of these results to the required temporal coherence and spatial uniformity for indirect laser drivers will be presented.

1. 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.

4P7

Soft X-Ray Production at Low Power, Low Intensity Experiments*

Robert L. Kauffman, Donald W. Phillion,
M. D. Rosen and C. J. Cerjan

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We have begun experiments to study x-ray production in the sub-kilovolt regime using small laboratory lasers optimizing source parameters for potential projection x-ray lithography systems. These systems will use multi-layer x-ray mirror technology for producing solid state devices. The present experiments are designed to measure absolute x-ray production in the region from 50-500 eV. The experiments use single 0.53 μm pulses with pulse widths of 5 ns to irradiate thick targets of various materials. Absolute x-ray yield around 100 eV is measured using VUV Si photodiodes coated with thin layers of Be to make them solar blind. A transmission grating/microchannel plate (TG/MCP) spectrometer is used to spectrally resolve the x rays. The Si diode output can be used to normalize the TG/MCP spectrum to obtain absolute yields over a large spectral range. Preliminary intensity scalings have been done for various Z targets. X-ray production efficiencies as high as 0.3%-eV^{-1} have been observed for Au at average intensities of about 10^{12} W/cm^2. Preliminary simulation results will be presented in a companion paper.

*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.

4P8

Twenty-First Annual Anomalous Absorption Conference
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Calculated Gain Profiles in Recombination X-Ray Lasers.

M. J. Dunning, P. Amendt, D. C. Eder, and C. J. Keane

Lawrence Livermore National Laboratory
University of California
Livermore, California 94550

Recent advances in optical laser technology have resulted in the development of high-intensity ($I > 10^{17}$ W/cm^2) short-pulse ($\tau < 100$ fs) lasers which admit the possibility of creating strongly non-equilibrium plasmas. It may now be possible to create a plasma of specific electron configuration directly via optical ionization with minimal heating of the ambient electrons. Lasing in such a plasma can occur in two regimes: a *transient* regime during which a rapid recombination cascade to the ground state takes place on radiative timescales and can result in significant population inversion; and the *quasi-static* regime characterized by the recombination timescales associated with the hydrodynamic and conductive cooling of the plasma.

A 1-D Lagrangian hydrodynamic code (DDP) has been used with a non-LTE detailed atomic configuration package (DCA) to examine the spatial and temporal dependent gain of the 4–3 transition of Lithium-like Neon in both the transient and quasi-static regimes. These results are compared with those obtained using a hydrogenic kinetics code in which a similarity solution for the hydrodynamics was assumed.

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

Development of Short Wavelength X-ray Lasers for Applications

L. B. Da Silva*, B. J. MacGowan, P. E. Young, D. C. Eder,
J. A. Koch, D. L. Matthews, S. Mrowka, and J. E. Trebes

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Our efforts have focused on the study of two x-ray lasers which have near term applications. The Ni-like Ta x-ray laser which operates at 44.83 Å is currently the best candidate for producing an x-ray hologram of a biological sample. For this reason we have been attempting to increase the output of this system by double passing the gain region. Initial results indicate that the multilayer mirror was being damaged before the peak of the laser pulse. Subsequent measurements of the x-ray flux and optical flux at the mirror indicate that scattered laser light is a significant problem. Optical intensities as high as 10^{10} W/cm^2 , well above the damage threshold have been measured. Evidence suggests that side scattered SBS may be a major component of the optical light. This is likely a consequence of the long scalelength produced along the axis of the x-ray laser amplifier. The Ne-like Yttrium x-ray laser is well suited for a variety of applications. The wavelength, 155 Å, is ideal for multilayer mirrors and reflectivities as high as 55% have been demonstrated. In order to evaluate this system for future nonlinear optics experiments measurements of the x-ray power, pulse width and line width have been made. The results of these measurements and their implications for future experiments will be discussed.

* Current Address: University of California at Berkeley

Work Performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48

Simulations of Soft X-Ray Production for Lithographic Applications*

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Soft X-ray production in a 4% energy range about 95 eV is simulated for a variety of materials and intensities. This energy band is desirable for potential projection X-ray lithography schemes. Preliminary measurements by Kauffman and Phillion used a single 530 nm pulse with a pulse width of 5.0 ns illuminating thick targets of gold, tin and molybdenum. The energy on target was 0.3 j with changing focal radius to vary the intensity. The overall production efficiencies were on the order of 0.1 - 0.3 % per eV with different intensity dependences for each material. These experimental features are reproduced in the simulations.

*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.

Presented at the 21st Anomalous Absorption Conference, Banff, Alberta 15th-19th April 1991.

X-ray Spectroscopic Studies of Germanium Plasmas Relevant to X-ray Laser Research.

J Dunn, H A Baldis, G D Enright, B La Fontaine, D M Villeneuve.

National Research Council of Canada, Ottawa, Ontario K1A 0R6.

J C Kieffer.

INRS-Energie, CP 1020, Varennes, Québec J3X 1S2.

We present x-ray spectroscopic studies (below 10 Å) of massive Germanium targets irradiated with 2 nsec (FWHM) pulses of 1.064 μm light from the *LP2* laser system. Spot (FWHM=150 μm) and line focus geometries were investigated with irradiances of 10^{13}-10^{15} W/cm^2. Flat PET(002) and ADP(101) crystal spectrometers ($\lambda/\Delta\lambda$=1000~3500) recorded the time-integrated L-shell resonance and continuum emission, in some cases with spatial resolution normal to the target surface. An x-ray pinhole camera (spatial resolution=20 μm) monitored the emission region of the plasma.

The electron temperature T_e is deduced by measuring the continuum spectrum emitted at energies greater than the ionisation potential of the highest observed charge state. The results are correlated with the F-like line emission and are compared with simultaneous Thomson scattering observations.

4P12

Abstract for the 21st Anomalous Absorption Conference
April 14-19, Banff Alberta, Canada

Time Resolved X-UV Spectroscopy of the rear side of laser illuminated thin foils at 0.26 mm

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Ecole Polytechnique 91128 Palaiseau, France

S. Hüller,
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We present time resolved X-UV spectra of the rear side of thin plastic foils coated on their front side with a thin layer of gold of different thicknesses (50 to 300 Å). The layers of gold must be sufficiently thin so that they will not perturb the heating of the foil by radiative effects. The plastic thickness is chosen equal to the ablation thickness of the material for the laser illumination conditions i.e about 6 μm. The spectrum emitted by the gold layer plays the role of a backlighter in order to probe the plastic heated by the laser. The time evolution of the transmitted spectrum in a range of wavelengths including the carbon K-edge shows the evolution of the thermal transport zone of the plastic heated by the laser. Comparisons with simulations including radiation (MULTI) confirm the weak effect of radiation heating particularly for the thinner layers of gold. They also permit simulating the front and rear spectra in the range of the experimental records to deduce the density and temperature profiles inside the thermal front and their time evolution.

Using X-ray Diagnostics for Time-Resolved Measurements of Specularly Scattered Laser Light*

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We recently became concerned about the intensity of specularly scattered laser light. For example, can the light incident on a planar Rayleigh-Taylor foil scatter onto the nearby x-ray backlighting target with sufficient intensity to confuse the experiment? To find out, we have fired a single Nova beam (0.35 μm) at CH targets at angles of incidence of 40 and 50 degrees. A gold disk (with fiducial holes) is placed in the specular direction, and x-rays from the gold disk are recorded with time-resolved x-ray pinhole cameras. The cameras can be calibrated by firing the laser directly at the gold disk, at known intensities. We have seen clear evidence of the specularly scattered light, especially in the first few hundred picoseconds. We have also measured the scattered light energy directly. These time-integrated (1 ns) measurements indicate that the total specularly scattered energy is low, of order 1% of the incident energy.

*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.

Non-Local Electron Transport — Effect on Emission Spectra From Laser-Irradiated Plasmas*

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When the mean free path of electrons at a few times thermal energy is not negligible compared to the temperature scale length, thermal transport becomes non-local in nature. This transport modifies the local Maxwellian distribution function. Based on LASNEX calculations of laser-generated gold plasmas, we calculate the position- and energy-dependent distribution function and, from this, the (not self-consistent) prediction of emission spectra.

*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

21st Annual Anomalous Absorption Conference
Banff, Alberta, Canada
April 14-19, 1991

THE ROLE OF ION MOMENTUM IN STIMULATED RAMAN SCATTERING

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It has been postulated recently,[1] that plasma drifts could alter the Langmuir-wave dispersion relation significantly and, hence, have important effects on parametric instabilities such as stimulated Raman scattering (SRS). To address this issue, a systematic study has been made of momentum conservation in SRS.[2] The time-averaged light-wave momentum is carried by the electromagnetic field, as is well known. However, in cold electron-ion plasma, none of the time-averaged Langmuir-wave momentum resides in the electrons; an ion drift is established which carries the Langmuir-wave momentum. This drift Doppler-shifts the Langmuir-wave frequency by a small amount, but does not impede SRS significantly. A related study of the detuning of relativistic Langmuir waves, in plasmas with arbitrary positive- to negative-ion mass ratios, is described and its implications for beat-wave particle acceleration are discussed briefly.

1. B. Amini, *Bull. Am. Phys. Soc.* 35, 1945 (1990).
2. C. J. McKinstrie and M. Yu, submitted to *Phys. Fluids B*.

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

Three-dimensional Alfven Waves in The Magnetosphere

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A three-dimensional resistive implicit magnetohydrodynamic simulation code is being constructed to study nonlinear mode conversion of Alfven waves at the Plasma Sheet Boundary Layer in the Earth's magnetosphere. Mode conversion of Alfven waves is responsible for resonant electric field structures which can be observed by spacecraft and inferred from data obtained from ground based radar. Preliminary results from the simulation code will be presented.

IN SEARCH FOR STABLE KINETIC ALFVEN SOLITONS

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The kinetic Alfven wave might play an important role in the heating and accelerating of auroral electrons. The 3-dimensional nonlinear equation describing the dynamics of the slow, shear kinetic wave in a homogenous, low ß plasma, was proposed by Das *et al*. Flat solitary solutions of this equation are known to be unstable. In searching for the stable solitons we shall obtain a symmetry group of the equation and construct some group-invariant solutions.

ORAL SESSION 5

W. Rozmus, Chair

PLASMA INTERACTIONS II

ROLE OF ION WAVE NONLINEARITIES IN THE STIMULATED BRILLOUIN SCATTERING

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The effect of ion wave nonlinearities on the saturation of stimulated Brillouin scattering (SBS) is investigated for wide range of plasma parameters. We extend previous calculations[1] for weak laser fluxes based on the frequency shift approximation into the regime of stronger ion nonlinearities described by the Korteweg - de Vries (KdV) equation. Reults obtained from the KdV/Maxwell equations are also compared with the predictions of the model including higher harmonics decomposition of ion waves[2]. Discussion includes: scaling laws for the reflectivity, transition from regular to random time behaviour of the reflected light, detailed analysis of the nonlinear ion waves driven by SBS.

For high laser fluxes we analyze the results obtained from the full set of ion fluid equations[3] and compare them with particle-in-cell calculations in order to investigate the role of kinetic effects on the nonlinear evolution of SBS driven sound waves.

complicated; not chaotic

1. M. Casanova, G. Laval, R. Pellat, and D. Pesme, Phys. Rev. Lett. **54**, 2230 (1985).
2. J. A. Heikkinen, S. J. Karttunen, and R. R. E. Salomaa, Phys. Fluids **27**, 707 (1984).
3. J. Candy, W. Rozmus, and V. T. Tikhonchuk, Phys. Rev. Lett. **65**, 1889 (1990).

* Permanent address: Department of Physics, University of Alberta, Edmonton, Canada.

The 21st Annual Anomalous Absorption Conference

Stimulated Brillouin Scattering from KrF-Laser-Produced Plasma

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An experimental study of stimulated Brillouin scattering from KrF laser produced plasmas is in progress. The 0.25μm wavelength laser pulses with duration of 1-3ns and energy of about 1J are focused to intensities of 10^{13} to 10^{14} W/cm^2 on solid target. SBS reflectivity, intensity threshold, and time-resolved spectrum ($\Delta\lambda$ = 0.1Å, Δt = 20ps) are measured for various target material (CH, Al, Au). The incident angle of the laser beam is varied (0, 22.5, 45, 60 degrees) to simulate increasing plasma scale length. Reflectivity as high as 3% is observed for Al targets at 45 degrees. Reflection from Au targets is measured to be several orders of magnitude lower than that from Al targets (large collisionality). Experimental results will be presented and compared with theoretical predictions of SBS generation via convective growth and absolute instability.

* Laser Fusion Project: Edmonton, Alberta, Canada

ION ACOUSTIC PARAMETRIC DECAY INSTABILITY IN LASER PRODUCED PLASMA WITH VARYING IONIC CHARGE*

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Studies of the ion acoustic decay instability[1,2] (IADI) are reported in which the target material of the (IR) laser-produced plasma was varied. The IADI was monitored by observing the Stokes peaks of the second-harmonic spectrum. Its threshold was quite low ($\approx 2\text{x}10^{13}$ W/cm^2) even in high Z plasma. The threshold increased only weakly with Z. On the other hand, the instability intensity decreased strongly with Z, which we attribute to the decrease of the growth rate. A simple theory explains our experimental results reasonably well.

The effective laser intensity is strongly reduced by the increased collisional-damping of epw in high Z plasma, so that the Stokes intensity was reduced strongly. Hence, strong electron heating due to the IADI is less likely in high Z plasma. On the other hand, in the context of the threshold, the collisional damping effect of the epw is canceled due to the opposite trend of the damping of the iaw which decreases with ZT_e/T_i. The low-threshold, and the sharp and steady spectrum may make the IADI a good diagnostic of local plasma conditions near the critical surface for high Z plasma.

* This work was supported by the National Laser Users Facility at the LLE, Univ. of Rochester, and the Plasma Physics Research Institute, UCD & LLNL.

1. K. Mizuno et al. Phys. Rev. Lett. 65, 428 (1990).
2. K. Mizuno et al. Phys. Fluids (1991).

PARAMETRIC DECAY AND CAVITON COLLAPSE IN IONOSPHERIC RADIO WAVE MODIFICATION EXPERIMENTS*

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In ionospheric radio wave modification experiments, one transmits a powerful HF electromagnetic(EM) radio wave from the ground,into the plasma. Among the experimental signatures, one observes enhanced "plasma lines" (scatter from Langmuir waves) in radar spectra of the excited turbulence.

The standard picture of the process responsible for the enhanced plasma line, has been in terms of parametric decay of the incident EM wave into electrostatic (ES) waves. This is the weak turbulence approximation (WTA) approach, where only three-wave interactions are allowed, hence, the daughter ES waves of the first decay can act as mother waves for a second decay, and so on. Recently, this understanding has been challenged. Instead, a "strong Langmuir turbulence" (SLT) theory has been proposed, describing the process as a large number of localized nucleation-collapse-burnout cycles.

In the present work, we present numerical solutions to a SLT model appropriate for ionospheric modification, namely a version of the Zakharov model (1 spatial dimension). This model contains the WTA as a limit, but in addition it extends into a region where the validity criteria for the WTA are no longer satisfied. The crucial parameters in this respect, are the frequency mismatch (difference between EM pump frequency and local plasma frequency), and the power contained in the EM pump. Close to the height where the pump frequency is equal to the local plasma frequency, the nucleation-collapse-burnout process dominates, while a distance below, the parametric decay cascade process dominates. We also find regions with coexisting parametric cascades and caviton collapse. In addition, we see an enhanced ion fluctuation level, not accounted for in the standard WTA theories applied to ionospheric modification.

The numerical results are compared to experimental results from the Arecibo radar in Puerto Rico, and from the EISCAT radar facility in Tromsoe, Norway.

*Talk to be given at the Twenty-First Annual Anomalous Absorption Conference, April 14-19, 1991, Banff, Alberta, Canada

COEXISTENCE OF CAVITON COLLAPSE AND PARAMETRIC DECAY CASCADES IN THE INTERACTION OF INTENSE COHERENT RADIATION WITH PLASMAS

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Recent observations, with improved space-time resolution, of the Langmuir turbulence excited by powerful HF radiation in the ionosphere provide persuasive evidence that caviton collapse can play an important role in the saturated state. At certain altitudes it appears that parametric decay cascades toward longer wavelengths can coexist with caviton collapse [1]. A high level of ion density fluctuations results from collapse. The cascades are truncated (compared to weak turbulence predictions) due to an effective Langmuir wave damping, which is larger than collisional, resulting from the coupling to cavitons and free ion density fluctuations. For stronger pumps the distinct cascade line structure disappears and the dominant dissipation is via caviton collapse. In the cascade regime cavitons appear to be driven by long wavelength Langmuir waves rather than directly by the pump. We expect that this physics should scale to apply, for sufficiently long scale lengths, to laser-plasma interactions. This scenario will be compared to observations of second harmonic emission spectra attributed to parametric decay instabilities near critical density and to decay cascades which originate from SRS-excited Langmuir waves. The latter studies will be compared to the "hard" saturation of the SRS Langmuir waves at the collisional parametric decay threshold recently proposed by Drake and Batha [2].

[1] D. F. DuBois, David Russell and Harvey A. Rose, Los Alamos Report LA-UR-90-3463.
[2] R. D. Drake and S. M. Batha, "The spectrum of saturated stimulated Raman scattering: evidence for an interpretation based on subsidiary Langmuir decay" (preprint 1990).

This work was performed under the auspices of the U. S. Dept. of Energy.

LOCAL THEORY OF SATURATED SRS IN 2-D

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The experimental effort on SRS for ICF has shifted from threshold effects to the properties of the saturated state of the instability. This work attempts to identify scaling laws for the light scatter which may be used for the mm-like plasmas expected in future targets [1].

As an aid in understanding these scaling laws theoretically, we solve the 2-D Zakharov model for the Langmuir turbulence for a given value of the scattered intensity. This approach relies on the local nature of the Langmuir turbulence on the scale of the scattered light profile. We compare the turbulence level with results of our 1-D global studies reported in this conference as a benchmark of those results. Using certain reduced models suggested by the 1-D work which depend on the local nature of the Langmuir turbulence, we outline a method in 2-D to achieve global self-consistency between the turbulence and the scattered light.

[1] R. P. Drake, Phys. Fluids B1, 1082 (1989).

This work was performed under the auspices of the U. S. Dept. of Energy.

GLOBAL MODEL OF PURE SRS COUPLED TO LANGMUIR WAVE TURBULENCE

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One dimensional simulation results are presented which illustrate the dependence of Stimulated Raman Scattering (SRS) upon plasma scale length and laser intensity. If the plasma is initially quiescent, there is a strong transient of SRS and strong Langmuir turbulence (SLT). After this transient has relaxed, in a time scale roughly determined by an ion acoustic transit time, different regimes of SLT are observed in different regions of the plasma.

In the region of the plasma furthest from the laser, where the backscattered Raman light has a small amplitude, regimes can be found corresponding to:

a) Langmuir wave amplitudes below the PDI threshold.
b) Langmuir wave amplitudes above the PDI threshold with saturation at one, two or three steps of the cascade.
c) SLT involving Langmuir wave collapse, coexisting with a truncated cascade.

The saturation of SRS, though significant, is not as "hard" as predicted by Drake and Batha [1] in the sense that a relatively small increase in SRS reflectivity corresponds to a much larger increase in the level of SLT. This implies that the level of backscattered light is not a good indicator as to the level of SLT and possible hot electron production, after the transient phase of evolution.

Comparisons with local models of SRS are favorable in strongly excited regimes.

[1] R. D. Drake and S. M. Batha, "The spectrum of saturated stimulated Raman scattering: evidence for an interpretation based on subsidiary Langmuir decay (preprint 1990).

This work was performed under the auspices of the U.S. Dept. of Energy.

OBSERVATIONS OF RESONANT ABSORPTION OF COMPRESSIONAL MAGNETOHYDRODYNAMIC WAVES IN THE EARTH'S MAGNETOSPHERE

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In a nonuniform magnetoplasma, compressional and shear Alfvén waves are coupled at the resonance region where the parallel (to the magnetic field) component of the phase velocity of the compressional Alfvén wave is equal to the local Alfvén speed. In analogy with resonant absorption in laser produced plasmas, the fast compressional wave plays the part of the electromagnetic wave, and the shear Alfvén wave plays the part of the electrostatic oscillations. The introduction of kinetic effects resolves the singularity on the resonant field line, and the coupling of the compressional mode to the shear wave then becomes a linear mode conversion problem, with mode conversion to kinetic Alfvén waves. We shall present observations of the ULF (1-3 mHz) electric fields associated with field line resonances in the magnetosphere. These fields are measured in the F-region by the Johns Hopkins University /APL HF radar at Goose Bay in Canada . We shall also present data from the CANOPUS network of magnetometers, meridian scanning photometers, and bistatic auroral radars which indicate that these resonances can sometimes be seen before the onset of polar magnetic and auroral substorm expansive phases. The auroral measurements suggest the possibility of the heating of electrons by kinetic Alfven waves, and the radar measurements of vortex structures in the plasma flow indicate the possible existence of nonlinear effects.

Electron Plasma Wave Breaking and Caviton Formation†

B. S. Bauer and A. Y. Wong

UCLA

Cavitons created under conditions of strong electron plasma wave (EPW) fields are investigated. The cavitons are made in the Small Caviton Device, a 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 in the shell where the driving frequency resonates with the local plasma frequency. The wave electric fields, measured with a diagnostic low-density 9 keV electron beam, grow to 100 times the original pump field. These highly-nonlinear EPW (electric field energy densities $W = E^2/4\pi n T_e > 10^3$), undergo wave breaking, producing electrons of energy $K > 10^3 T_e$. Both the wave amplitude and phase profiles are measured, allowing reconstruction of the wave in light of cold-fluid theory, and calculation of the expected accelerated-electron energy. This is compared with the experimental gridded energy analyzer measurement, and an attempt is made to obtain scaling laws for the energetic-electron spectrum.

The strong, localized electric fields eject electrons from the resonant region, driving up the space potential at the resonant layer by $\Delta\phi > 100 T_e$. Ions are expelled both by this ambipolar force, and by the inherent spatial polarization of the localized EPW. This results in ion acoustic shock waves, and a cylindrical-shell density depression, or "caviton." The sources of ion acceleration (ponderomotive force of the wave on the electrons, ejection of electrons via wave breaking, spatial polarization of localized EPW) are examined.

Finally, the experimental results are compared with those from a one-dimensional particle-in-cell computer simulation, tailored to closely reflect the experiment.

†Work supported by UCLLNL B083562.

Charged Particles as Carriers of the Electrostatic Wave Momentum in Plasmas and their Effects

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It is shown that charged particles are the carriers of the momentum of electrostatic plasma waves. Accordingly, the electrons will have a drift in a plasma sustaining electrostatic electron waves. This has lead to the discovery of an electron drift in a plasma sustaining the electrostatic electron waves. Applications of this drift and its effects on both magnetically confined and inertially confined plasmas are discussed. It will be shown that the displacement and conduction currents in the electrostatic electron waves do not cancel and as a result a correction term should be added to the previously known dispersion relations. A method is proposed to drive toroidal current by electron waves to confine plasma in a tokamak fusion reactor. This method, in contrast to the lower hybrid current drive, does not depend on auxiliary mechanisms such as Landau resonance for generating current. Also, its current drive efficiency is optimum.

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