22nd Annual Anomalous Absorption Conference

Whiteface Inn Resort
Lake Placid, New York
12–17 July 1992

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Twenty-Second Annual

Anomalous Absorption Conference

Whiteface Inn Resort
Lake Placid, New York
July 12-17, 1992

Hosted by the University of Rochester
Laboratory for Laser Energetics

Conference Co-Chairs:	Wolf Seka
	Stephen Craxton
	David Meyerhofer
Conference Coordinator:	Susan Thatcher

Twenty-Second Annual Anomalous Absorption Conference

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PROGRAM

------------------ Morning Session, Monday, July 13, 8:30 A.M. ------------------ (W. L. Kruer, Chair)

ORAL SESSION - Plasma Interactions I
(15 minutes each)

8:30 Introduction and Welcome
R. L. McCrory, W. Seka.

8:45 101 The Angular Variation of Stimulated Brillouin Scattering from Plasmas with Weak but Finite Velocity Gradients;
R.P.Drake, K.S. Bradley, S.H. Batha, D.S. Montgomery, K. Estabrook, H.A. Baldis, T.W. Johnston, R. L. Berger, W.L. Kruer, and R. Procassini.

9:00 102 Two-Plasmon-Decay Instability and Raman Scattering in Long-Scale-Length Laser Plamas;
W. Seka, R.E. Bahr, R.S. Craxton, R.W. Short, A. Simon, D.S. Montgomery, and A. Rubenchik.

9:15 103 Effect of Controlled Modulations on the Interaction of Smoothed and Unsmoothed Laser Beams with Coronal Plasmas;
L.A. Gizzi, T. Afshar-Rad, V. Biancalana, P. Chessa, C. Danson, A. Giulietti, D. Giulietti, E. Schifano, S.M. Viana, and O. Willi.

9:30 104 Collective Thomson Scattering from the Ion Acoustic Decay Instabilities in Laser Produced Plasma;
K. Mizuno, B. Sleaford, R.P. Drake, K. Baker, B. Bauer, D.M. Villeneuve, and B. La Fontaine.

9:45 105 Spatiotemporal Chaos in the Langmuir Decay and its Implications on the Saturation of SRS;
C. Chow, A. Bers, and A.K. Ram.

10:00 Coffee Break

10:30 106 Excitation of Stimulated Raman Scattering in Laser Hot Spots and its Nonlinear Saturation;
B. Bezzerides, D. DuBois, and H. Rose.

10:45 107 Saturation of Stimulated Raman Scattering by the Excitation of Langmuir Turbulence;
D. DuBois, H. Rose, and B. Bezzerides.

11:00 108 Signatures of Caviton Collapse Observed in RF Modification of the Ionosphere;
D. Russell, D. DuBois, and H. Rose.

11:15 109 Parametric Instability Driven by a Random Phase Plate Laser Beam;
R. L. Berger.

11:30 1O10 Radial Thermal Transport Experiments in Laser-Produced Exploding-Foil Plasmas;
D.S. Montgomery, O.L. Landen, K.G. Estabrook, H.A. Baldis, S.H. Batha, K.S. Bradley, R.P. Drake, and R.J. Procassini.

11:45 1O11 Large Bandwidth Frequency-Converted Nd:Glass Laser at 527 nm with $\Delta\upsilon/\upsilon = 2\%$;
D. Eimerl, D. Milam, and J. Yu.

12:00 Lunch

------------------ Evening Session, Monday, July 13, 7:30 P.M. ------------------ (R.S. Craxton, Chair)

REVIEW TALK (45 minutes)

1R1 Cryogenic Target Experiments with GEKKO XII 8 kJ, 527 nm Laser System;
K.A. Tanaka, T. Yamanaka, K. Nishihara, T. Norimatsu, M. Nakai, R. Kodama, M. Nakatsuka, T. Kanabe, T. Jitsuno, H. Azechi, K. Mima, N. Miyanaga, A. Nishiguchi, H. Takabe, C. Chen, M. Kado, M. Katayama, M. Tsukamoto, C. Yamanaka, and S. Nakai.

MIXED POSTER SESSION

1P1 Development of a Non-LTE Spectral Post-Processor for Dense Plasma Simulations with Application to Spectroscopic Diagnostics in Spherical Implosions at Nova;
N.D. Delamater, G.D. Pollak, A.A. Hauer, D.B. Harris, C.J. Keane, B.A. Hammel, and L.V. Powers, and J.K. Nash.

1P2 Analysis of Time-Integrated and Time-Resolved Capsule Symmetry Experiments on Nova;
L.V. Powers, L.J. Suter, D. Ress, and A. Hauer.

1P3 Spatial Dependence of X-ray Conversion Efficiency in Laser-Driven Plasmas;
F. Ze, R.L. Kauffman, J.D. Kilkenny, R. Wallace, J.L. Bocher, J.L. Bourgade, and D. Juraszek.

1P4 Early Time Effects in X-ray Production from Laser-Irradiated High Z Plasmas;
R.L. Kauffman, F.N. Ze, D.S. Montgomery, A.R. Thiessen, L.J. Suter, J.L. Bocher, J.L. Bourgade, and D. Juraszek.

1P5 Time- and Space-Resolved Density and Temperature Profiles from Aluminum K-shell Spectra;
U. Ellenberger, B. Soom, A. Glinz, and J.E. Balmer.

1P6 Spectroscopic Electron-Temperature Diagnosis of Optically Thick Exploding-Foil Plasma in the Presence of an Intense Radiation Field;
T.D. Shepard, C.J. Keane, L.J. Suter, and J. Abdallah, Jr.

1P7 The Effects of Radiation Transport on Line Ratios used as Temperature and Density Diagnostics;
S.H. Langer and C. Keane.

1P8 Observation of Modulational Instability in Nd-Laser Beat-Wave Experimemnts;
J.R. Marquès, F. Amiranoff, M. Laberge, F. Moulin, E. Fabre, B. Cros, G. Matthieussent, P. Benkheiri, F. Jacquet, C. Gregory, Ph. Miné, B. Montes, P. Poilleux, J. Meyer, P. Mora, and C. Stenz.

1P9 Particle Acceleration in a Relativistic Wave in the Adiabatic Regime;
P. Mora.

1P10 The Group Velocity Of Large Amplitude Electromagnetic Waves;
C.D. Decker and W.B. Mori.

1P11 Wake-Field Effect Induced by a Short Laser-Pulse in a Plasma:
Limits of the Plasma Wave Amplitude;
D. Teychenné, G. Bonnaud, and J.L. Bobin.

1P12 Stimulated Brillouin Reflectivity in Short Pulse Experiments;
Ph. Mounaix, M. Casanova, T. Kolber, D. Pesme, and W. Rozmus.

1P13 Stimulated Brillouin and Raman Back/Forward Scattering Induced by a Short Laser Pulse Inside a Homogeneous Plasma;
G. Bonnaud.

1P14 Backscattered Radiation, Cooling, and Focusing of Electron Beams Using Intense Laser Fields;
E. Esarey and P. Sprangle.

1P15 Interaction of Ultra-Intense Light with Underdense Plasmas;
W.L. Kruer, S.C. Wilks, and A.B. Langdon.

1P16 Third-Harmonic Generation with Ultra-High Intensity Laser Pulses;
J.M. Rax and N.J. Fisch.

1P17 Relativistic Harmonic Generation in Underdense Plasmas;
W.B. Mori and C.D. Decker.

1P18 Incoherent Harmonic Emission from Strong Electromagnetic Waves in Plasmas;
C.I. Castillo-Herrera and T.W. Johnston.

1P19 Propagation of a Spatially Incoherent Laser Beam in an Underdense Plasma;
D.E. Hinkel-Lipsker and E.A. Williams.

1P20 Statistical Properties of Laser Hot Spots Produced by a Random Phase Plate;
H.A. Rose and D.F. DuBois.

1P21 Quasilinear Diffusion of Photons in an ISI Beam;
A.J. Neil and E.R. Tracy.

1P22 Landau-Fluid Simulation of Laser Filamentation;
T.B. Kaiser, B.I. Cohen, R.L. Berger, B.F. Lasinski, A.B. Langdon, and E.A. Williams.

1P23 Effect of Beam Smoothing on Filamentation;
B.F. Lasinski, R.L. Berger, A.B. Langdon, E.A. Williams, W.L. Kruer, T.B. Kaiser, and B.I. Cohen.

1P24 Studies of Thermal Filamentation with Nonlocal Thermal Conductivity;
A.J. Schmitt.

1P25 Nonlocal Heat Transport in Spherical Plasmas using the Fokker-Planck code SPARK;
P. Amendt, L. Powers, L. Suter, and E.M. Epperlein.

1P26 O. Peyrusse, Inclusion of Stark Effect in Collisional-Radiative Model Coupled to Line Transfer — Application to the Computation of X-ray Emission of a Laser-Imploded DT-Argon Filled Capsule

----------------- Morning Session, Tuesday, July 14, 8:30 A.M. ----------------- (D.D. Meyerhofer, Chair)

ORAL SESSION - Ultrashort Pulse Interactions I
(15 minutes each)

8:30	2O1	X-ray Emission from Femtosecond Laser-Produced Plasmas; *P. Audebert, J.P. Geindre, F. Falliès, A. Rousse, J.C. Gauthier, A. Mysyrowicz, G. Grillon, J.P. Chambaret, and A. Antonetti.*
8:45	2O2	Femtosecond Dynamics of a High-Intensity Laser-Plasma Interaction; *D. Umstadter and X. Liu.*
9:00	2O3	Measurements of the P-Polarized Intensity Enhancement in High-Contrast, Picosecond Laser-Produced Plasmas; *S. Uchida, H. Chen, Y.-H. Chuang, J.A. Delettrez, and D.D. Meyerhofer.*
9:15	2O4	K_α Emission from High-Contrast, Picosecond Laser-Plasma Interactions; *H. Chen, J.A. Delettrez, B. Soom, S. Uchida, B. Yaakobi, and D.D. Meyerhofer.*
9:30	2O5	Effect of the Ponderomotive Force on Fast Ions in Short Scale-Length Laser-Plasma Interactions; *J.A. Delettrez, S. Gutstein, S. Uchida, and D.D. Meyerhofer.*
9:45	2O6	Time Resolved keV Spectroscopy of Ultrashort Plasmas; *J.C. Kieffer, M. Chaker, Y. Beaudoin, C.Y. Côté, H. Pépin, C.Y. Chien, S. Coe, and G. Mourou.*
10:00		Coffee Break
10:30	2O7	Absorption of Intense Subpicosecond 1.06 μm Laser Light by Solid Targets; *D.E. Klem, C. Darrow, S. Lane, and M.D. Perry.*
10:45	2O8	Strongly Coupled Stimulated Raman Backscatter from Sub-Picosecond Laser-Plasma Interactions; *C.B. Darrow, C. Coverdale, M.D. Perry, W.B. Mori, C. Clayton, K. Marsh, and C. Joshi.*
11:00	2O9	Measurements of the Angular Distribution and Spectral Shape of the Hard X-ray Emission from a 100 Femtosecond Laser Plasma; *D. Price, R. Shepherd, D. Gold, L. Van Woerkom, R. Walling, and W. White.*
11:15	2O10	Fokker-Planck Simulations of Short Pulse Experiments; *R.P.J. Town and A.R. Bell.*
11:30	2O11	The Interaction of Ultra-Short Powerful Laser Pulse with Solid Target: Ion Expansion and Acceleration; *E.G. Gamaly.*
11:45	2O12	High-Intensity, Ultra-Short Pulse Laser Plasma Interactions; *S.C. Wilks and W.L. Kruer.*
12:00		Lunch

------------------ Evening Session, Tuesday, July 14, 7:30 P.M. ------------------ (R.L. McCrory, Chair)

REVIEW TALK (45 minutes)

2R1 Non Local Transport in Laser Fusion Plasmas;
E.A. Williams.

MIXED POSTER SESSION

2P1 Nonlinear Plasma Wave Excitation in the Microwave Range;
B. Cros, A. Chiron, J. Godiot, and G. Matthieussent.

2P2 Finite Bandwidth Effects on Stimulated Brillouin Scattering in Inhomogeneous Plasmas;
P.N. Guzdar, C.S. Liu, and R.H. Lehmberg.

2P3 Two Dimensional Simulations of Stimulated Brillouin Scattering and Filamentation Instability in Laser Produced Plasmas;
M.R. Amin, C.E. Capjack, P. Frycz, W. Rozmus, and V.T. Tikhonchuk.

2P4 Numerical Simulation of the $2\omega_{pe}$ Instability;
Y.A. Omelchenko and A.M. Rubenchik.

2P5 Observation of SRS at λ_L = 527 nm with Random Phased Plates;
M. Tsukamoto, K.A. Tanaka, M. Kado, M. Nakai, T. Norimatsu, A. Nishiguchi, K. Mima, K. Nishihara, T. Yamanaka, and S. Nakai.

2P6 The Interpretation of Stimulated Raman Scattering from Previous Laser-Produced Plasma Experiments;
K.L. Baker, R.P. Drake, and S.H. Batha.

2P7 Random Phase Plate Effects on SBS Emission from Nova Two-Beam Exploding Foils;
J.D. Moody, H.A. Baldis, D.S. Montgomery, S. Batha, R. Berger, K. Estabrook, W.L. Kruer, C. Labaune, S. Dixit, and R. Procassini.

2P8 A Multi-Channel Time Resolved Thomson Scattering Diagnostic to Investigate the Ion Acoustic Decay Instability;
B. Sleaford, K. Mizuno, R.P. Drake, K. Baker, B. Bauer, D.M. Villeneuve, and B. LaFontaine.

2P9 Detailed 266 nm Thomson Scattering Measurements of a Laser Heated Plasma;
M.D. Tracy, J.S. De Groot, K.G. Estabrook, and S.M. Cameron.

2P10 Kinetic and Hydrodynamic Simulations of Interpenetrating Laser-Produced Plasmas;
R.J. Procassini and P.W. Rambo.

2P11 Kinetic Simulation of a Plasma Collision Experiment;
O. Larroche.

2P12 Simulations of High Density Colliding Plasma Slabs Using a Hybrid Particle-in-Cell Model with Interparticle Collisions;
M.E. Jones and V.A. Thomas.

2P13 Numerical Study of Interpenetrating Plasma Streams Using a 1D Eulerian Multi-Phase Code;
A. Decoster, M. Demoulins, and G. Schurtz.

2P14 Fluid Equations for Interpenetrating Plasmas;
A. Decoster.

2P15 A Search for Gain in a Ni-Like Tin Plasma;
G.D. Enright, J. Dunn, D.M. Villeneuve, S. Maxon, A.L. Osterheld, H.A. Baldis, B. La Fontaine, J.C. Kieffer, M. Nantel, and H. Pépin.

2P16 Measuring the Ion Temperature in X-ray Laser Plasmas;
B. La Fontaine, J. Dunn, H.A. Baldis, G.D. Enright, H. Pépin, and D.M. Villeneuve.

2P17 ~~Modeling of the Output Beam in X-ray Lasers;~~ → Withdrawn
~~*M.T.M. Lightbody, P.B. Holden, and G.J. Pert.*~~

2P18 Methods for Increasing the Gain Coefficient of Short Wavelength Collisional X-ray Lasers;
S. Maxon and D.C. Eder.

2P19 Opacity Model Sensitivity of Diagnostic Witness Plates;
J. K. Nash, R. J. Olness, and S. P. Hatchett II.

2P20 Rosen from 505

------------------ Morning Session, Wednesday, July 15, 8:30 A.M. ------------------ (C.E. Capjack, Chair)

ORAL SESSION - Hydrodynamics and Diagnostics
(15 minutes each)

8:30 3O1 Hybrid Direct/Indirect Drive target;
S.V. Coggeshall.

8:45 3O2 A Numerical Investigation of NIKE Target Edge Effects;
J.P. Dahlburg, J.H. Gardner, and M.H. Emery.

9:00 3O3 Increasing X-ray Conversion Efficiency by Shifting the Power Balance;
L.J. Suter, A.R. Thiessen, R.L. Kauffman, and M. Cray.

9:15 3O4 Effects of Long Wavelength Laser Intensity Asymmetries of ICF Pellet Implosions at Moderate Convergence Ratio;
J.H. Gardner and J.P. Dahlburg.

9:30 3O5 3D Rayleigh-Taylor Calculations;
J. Hecht, D. Ofer, D. Shvarts, S.A. Orszag, and R.L. McCrory.

9:45 3O6 Richtmyer-Meshkov Experiments on Nova at High Compression;
G. Dimonte and B. Remington.

10:00 Coffee Break

10:30 3O7 Opacity Effects in Indirect-Drive Rayleigh-Taylor Experiments on Nova;
B.A. Remington, S.V. Weber, and R.J. Wallace.

10:45 3O8 Target Design for Testing the New Los Alamos Nova Ion-Temperature Diagnostic;
D. Harris and R. Chrien.

11:00 3O9 Emission Spectroscopy of L-shell Xenon as an Electron Temperature and Density Diagnostic;
C.J. Keane, B.A. Hammel, A.L. Osterheld, and D.R. Kania.

11:15 3O10 The Role of Continuum Lowering in Opacity Calculations for Simulations of Diagnostic Spectra;
R. Epstein, B. Yaakobi, and F.J. Marshall.

11:30 3O11 Refractive Image Distortion ---- An Alternative to Interferometry for Characterizing Long-Scale-Length Plasmas;
R.S. Craxton and F.S. Turner.

12:00 Lunch

------------------ Evening Session, Wednesday, July 15, 6:30 P.M. ------------------ (W. Seka, Chair)

6:30 Banquet

8:00 Business Meeting

8:15 3R1 Crossing the Desert Beyond the Standard Model with the SSC;
R.K. Adair.

------------------ Morning Session, Thursday, July 16, 8:30 A.M. ------------------ (B. Bezzerides, Chair)

ORAL SESSION - Plasma Interactions II
(15 minutes each)

8:30 4O1 Thermal Stimulated Brillouin Scattering in Laser-Produced Plasmas;
R.W. Short and E.M. Epperlein.

8:45 4O2 The Stimulated Brillouin Scattering Threshold in a Homogeneous CH Plasma;
D.D. Meyerhofer, A.C. Gaeris, and R.W. Short.

9:00 4O3 Can Transient Heat Flow Induce Blue-Shifted SBS?;
J.S. De Groot, W.L. Kruer, and H.A. Baldis.

9:15 4O4 The Effect of Weak Electron-Ion Collisions on Ion-Sound Wave Damping;
A. Simon, E.M. Epperlein, and R.W. Short.

9:30 4O5 Damping of Ion-Acoustic Waves in the Presence of Electron-Ion Collisions;
E.M. Epperlein, R.W. Short, and A. Simon.

9:45 4O6 The Nonlinear Detuning of Multiwave Interactions;
C.J. McKinstrie, X.D. Cao, and J. Li.

10:00 Coffee Break

10:30 4O7 The Theory of the Mixed-Polarization High Frequency Instability in Inhomogeneous Plasmas;
B.B. Afeyan and E.A. Williams.

10:45 4O8 Breaking of Resonantly Excited Electron Plasma Waves - Solved;
A. Bergmann and P. Mulser.

11:00 4O9 Instability Threshold Analysis for Laser-Irradiated Flat Targets;
J.M. Wallace and M. Cray.

11:15 4O10 Plasma Wave Generation in Beat-Wave Experiments with Nd Lasers;
F. Amiranoff, M. Laberge, J.R. Marquès, F. Moulin, E. Fabre, B. Cros, G. Matthieussent, P. Benkheiri, F. Jacquet, C. Gregory, Ph. Miné, B. Montes, P. Poilleux, J. Meyer, P. Mora, and C. Stenz.

12:00 Lunch

------------------ Evening Session, Thursday July 16, 7:30 P.M. ------------------ (R.L. Kauffman, Chair)

REVIEW TALK (45 minutes)

4R1 Cryogenic Layers, 10 nm Surfaces, and Other Perplexities of ICF Targets;
T.P. Bernat

MIXED POSTER SESSION

4P1 Ion Kinetic Simulations of Shock Wave Formation and Propagation;
F. Vidal, J.P. Matte, M. Casanova, and O. Larroche.

4P2 Three Dimensional Simulations of the Rayleigh-Taylor Instability in the Deceleration Phase;
R.P.J. Town, B.J. Jones, and A.R. Bell.

4P3 Mixing Induced by Hydrodynamic Instabilities in a Laser-Driven Planar Experiment;
H. Croso, D. Galmiche, P.A. Holstein, B. Meyer, and F. Mucchielli.

4P4 A Self-Similar Model for Laser Driven Ablation;
T. Tlusty, E. Waxman, and D. Shvarts.

4P5 Numerical Analysis of Nonlinear Mode-Mode Interactions in the Rayleigh-Taylor Instability;
D. Ofer, J. Hecht, D. Shvarts, Z. Zinamon, and S.A. Orszag.

4P6 A Numerical Evaluation of Preformed Plasma Effects on Spherical Pinch Inertial Confinement;
M. Lamari, E. Panarella, S. Aithal, and B. Hilko.

4P7 The Spherical Pinch as an X-ray Emitter: A Numerical Study;
M. Lamari, E. Panarella, S. Aithal, and B. Hilko.

4P8 Microinstability Inhibited Heat Flow and Microinstability Enhanced Non-Maxwellian Distributions in Laser-Produced Plasma ICF and X-ray Laser Experiments;
K.G. Whitney and P.E. Pulsifer.

4P9 Ponderomotive Force of a Uniform Electromagnetic Wave in a Time Varying Dielectric Medium;
W.B. Mori and T. Katsouleas.

4P10 Electron Plasma Wavebreaking and Caviton Formation;
B.S. Bauer.

4P11 A Variational Approach to Parametric Instabilities in Inhomogeneous Plasmas;
B.B. Afeyan and E.A. Williams.

4P12 Studies of Stimulated Brillouin Scattering Using a Hybrid Particle Ion/Fluid Electron Code;
S.C. Wilks, W.L. Kruer, R. Berger, E.A. Williams, and J. Denavit.

4P13 Transversal Chirp in SRS Pulses;
J. Teichmann.

4P14 Saturation of Stimulated Raman Scattering by Langmuir and Sound Wave Coupling;
T. Kolber, W. Rozmus, and V.T. Tikhonchuk.

4P15 Spatiotemporal Chaos in the Three-Wave Interaction;
C. Chow, A. Bers, and A.K. Ram.

4P16 Nonlinear Oscillation and Chaos in Backward Four-Wave Mixing;
J. Li, C.J. McKinstrie, and A.L. Gaeta.

4P17 Nonlinear Schrodinger Self-Focusing in Plasmas: The Core and the Halo;
F. Vidal and T. Johnston.

4P18 Observations of MeV Electrons and Scattered Light in Intense, Subpicosecond Laser-Plasma Interactions;
C.B. Darrow, S. Lane, D. Klem, M.D. Perry, and K. Marsh.

4P19 X-ray Line Polarization Spectroscopy of Laser Produced Plasmas;
J.C. Kieffer, J.P. Matte, H. Pépin, M. Chaker, Y. Beaudoin, C.Y. Côté, C.Y. Chien, S. Coe, G. Mourou, and J. Dubau.

4P20 Self-Guiding of a Subpicosecond Laser Pulse in a Neutral and Ionized Gas;
X. Liu and D. Umstadter.

4P21 K-shell Emission from 140 Femtosecond Laser-Produced Plasmas Created from Porous Aluminum Targets;
R. Shepherd, D. Price, B. White, S. Gordan, A. Osterheld, R. Walling, D. Slaughter, and R. Stewart.

4P22 Picosecond-Plasma Temperature Measurements by Ratio of Isoelectronic Lines;
R.S. Marjoribanks, F.W. Budnik, H. Chen, and D.D. Meyerhofer.

4P23 The Evolution of Electromagnetic Pulses in Two-Dimensions;
C.D. Decker, W.B. Mori, J.J. Su, T. Katsouleas, and T.C. Chiou.

4P24 Electron Kinetic Simulations of Intense, Ultra-Short Laser Pulse Interaction with Solid Targets;
J.P. Matte, S. Ethier, J.C. Kieffer, M. Chaker, and H. Pépin.

4P25 Interaction of the Short Powerful Electromagnetic Pulse with Dense Plasma Layer;
L.V. Borodachev and V.T. Tikhonchuk.

------------------ Morning Session, Friday July 17, 8:30 A.M. ------------------ (J.P. Dahlburg, Chair)

ORAL SESSION - X-ray Lasers; Ultrashort Pulse Interactions II
(15 minutes each)

8:30 5O1 Space- and Time-Resolved Study of Ne-like Emissions in Ge X-ray Lasers;
M. Nantel, J.C. Kieffer, H. Pépin, J. Dunn, G.D. Enright, D. Villeneuve, H.A. Baldis, and B. La Fontaine.

8:45 5O2 Optimized Coherence in Single-Stage X-ray Lasers;
P. Amendt, R.A. London, and M. Strauss.

9:00 5O3 Measurements of Coherence and Beam Patterns in Yttrium X-ray Lasers;
R.Walling, G.M. Shimkaveg, M.R. Carter, R.E. Stewart, J.E. Trebes, R.A. London, A.L. Osterheld, R.P. Ratowsky, R.S. Craxton, M.D. Feit, L.B. Da Silva, B.J. MacGowan, and D.L. Matthews.

9:15 5O4 Time-Dependent Ray and Wave Optics Modeling of X-Ray Propagation in Exploding Foil Line-Focus Laser Plasmas;
R.P. Ratowsky, R.S. Craxton, M.D. Feit, R.A. London, R.Walling, A.L. Osterheld, G.M. Shimkaveg, and M.R. Carter.

9:30 505 Effects of Plasma Dispersion in Ultra-short Pulse X-ray Lasers;
M. D. Rosen, P. Amendt, D.C. Eder, and R. A. London

9:45 506 Intense Laser Pulse Propagation and Wakefield Generation in Plasma;
E. Esarey, P. Sprangle, J. Krall, and G. Joyce.

10:00 507 Self Focusing and Raman Scattering of Ultra Short Laser Pulses in Tenuous Plasmas;
P. Mora and T.M. Antonsen Jr.

10:15 508 High-Harmonic Generation from Femtosecond Laser-Irradiated Solids;
S. Hüller and J. Meyer-ter-Vehn.

10:30 509 The Dense Plasma Heating by Ultrashort Powerful Laser Pulses in the Regime of an Anomalous Skin Effect;
A.A. Andreev, E.G. Gamaly, V.N. Novikov, W. Rozmus, A.N. Semakhin, and V.T. Tikhonchuk.

10:45 Coffee Break

ORAL SESSION I

W.L. Kruer, Chair

Monday July 13

PLASMA INTERACTIONS I

The angular variation of Stimulated Brillouin Scattering from plasmas with weak but finite velocity gradients:

R.P. Drake,[1,2] K.S. Bradley,[1,2] S.H. Batha,[1] D.S. Montgomery,[3] Kent Estabrook,[4] H.A. Baldis,[3] T.W. Johnston,[5] R.L. Berger,[4] W.L. Kruer,[4] R.Procassini[4]

(1) Plasma Physics Research Institute, Lawrence Livermore National Laboratory and University of California Davis, Livermore CA 94551

(2) Department of Applied Science, University of California Davis, Davis CA 95616

(3) Laser Directorate, ICF Program, Lawrence Livermore National Laboratory, Livermore CA 94551

(4) Physics Department, X-division, Lawrence Livermore National Laboratory, Livermore CA 94551

(5) INRS-Energie, Varennes, Quebec, Canada, J3X 1S2

We have used the Nova laser to study the development of stimulated Brillouin scattering (SBS) in plasmas of comparatively low density and shallow velocity gradient. By using about 24 kJ of energy in 8, 0.35 μm wavelength laser beams we were able to explode a thin (0.5 - 1.5 μm) titanium target so as to produce plasmas having maximum densities of ~ 0.02 - 0.15 critical and T_e ~ 3 keV, with density profiles of FWHM > 1.2 mm and velocity gradients below $10^9 s^{-1}$. We then used a laser beam of 0.53 μm wavelength to drive SBS in such plasmas at average intensities from below 10^{14} W/cm^2 to above 10^{15} W/cm^2. Such experiments explore a unique regime for SBS, where the instability is weakly driven in a weakly-perturbed plasma and where the myriad of coupling effects that are possible near quarter-critical and critical density are not present. In addition, the experiments are of practical interest as similar conditions will be present in the plasmas of high-gain laser-fusion targets.

We have measured the time-resolved spectrum of the spectral intensity of SBS at several angles using a multi-angle spectrometer system, calibrated by photodiodes. The angular variation shows several features, discussed here. Under some conditions, the emission near backscatter is many orders of magnitude above the level predicted by convective theory, which would be thought to apply here. In contrast, in the near-forward directions there is ample convective gain to produce the observed signals, although sufficiently near foward scattering the role of filamentation is not yet clear. The details of the spectra show systematic changes vs angle as well. At oblique angles, the strongest emission is delayed relative to that near forward or backward. The spectrum also evolves differently in time at different angles. In sum, these data pose substantial challenges for theoretical explanation.

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.

Two-Plasmon-Decay Instability and Raman Scattering in Long-Scale-Length Laser Plasmas

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Using long-scale-length plasmas generated by multiple-beam irradiation of mass-limited flat targets, we have investigated sub-quarter critical interaction phenomena at $\lambda_L = 351$ nm. Concentrating on the two-plasmon-decay (TPD) instability and stimulated Raman scattering, we have found that the TPD instability threshold (~2–4 × 10^{13} W/cm^2) is approximately 10 times lower than that obtained from the conventional (self-scattered) 3/2 harmonic emission. Above several 10^{14} W/cm^2, we observe stimulated Raman scattering from densities well below the peak of the "parabolic" (center-peaked) density profile as long as this peak density is above the Landau cutoff of the TPD instability at ~$n_c/5$. Furthermore, the stimulated Raman emission originates from a rapidly decreasing density region independent of the evolution of the background plasma density. We will present experimental data supporting these conclusions and discuss various attempts at explaining these observations.

This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under agreement No. DE-FC03-85DP40200 and by the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics, which is sponsored by the New York State Energy Research and Development Authority and the University of Rochester.

EFFECT OF CONTROLLED MODULATIONS ON THE INTERACTION OF SMOOTHED AND UNSMOOTHED LASER BEAMS WITH CORONAL PLASMAS

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An experimental study has been performed very recently at the Rutherford Appleton Laboratory (UK) using the "Vulcan" laser facility. Four 600ps, 1054nm beams were focused on 400μm diameter 500nm thick aluminium targets at an irradiance of $\cong 1.5\times10^{13}$Wcm^{-2} in order to preform a plasma. A fifth narrow-band or broad-band beam interacted with the preformed plasma with a given delay. A sixth 100ps, 527nm pulse was used as a probe beam for interferometric measurements of the plasma density distribution. Plasma electron temperature before and during the interaction was obtained by means of X-ray time-resolved spectroscopy.
The laser intensity distribution in the focal spot of the interaction beam was manipulated

of 100μm. The effect of such laser intensity gradients on filamentation instability was investigated by means of time-resolved spectroscopy of Second Harmonic emission (SH) and Stimulated Brillouin Back-Scattering as well as time-resolved imaging of SH emission. Finally we studied the effect of laser beam smoothing techniques including RPP (narrow-band), ISI and SSD (broad-band) on this interaction regime.

Collective Thomson Scattering from the Ion Acoustic Decay Instabilities in Laser Produced Plasma*

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We have extensively studied the Ion Acoustic Decay Instability[1] (IADI) in laser produced large scale plasmas. Our results not only raise important issues for ICF target design, but also show the properties of the local plasma near the critical density can be effectively diagnosed using the IADI. We have developed a time-resolved, multi-channel collective Thomson scattering system to study the scattering from the ion acoustic waves and electron plasma waves excited by the IADI. A 1.06 μm laser (~ 100J) is normally incident on a thin (~ 1 μm) CH target. A 3ω probe beam (~ 1J) is applied at an angle of 63 degree to the interaction laser beam. The 6-channel detector is used to measure the scattered signal at angles 93, 101, 109, 117, 125, and 133 degree. The collective Thomson scattering from the ion acoustic waves is studied. Clear scattering signals are observed at the Stokes side.

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1. K. Mizuno et al, Phys. Rev. Lett. 23, 428 (1990), Phys. Fluids B3, 1983 (1991), and in Laser Interaction and Related Plasma Phenomena, Vol. 10, edited by H. Hora and G. H. Hiley.(1992)

SPATIOTEMPORAL CHAOS IN THE LANGMUIR DECAY AND ITS IMPLICATIONS ON THE SATURATION OF SRS

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The space-time evolution of the non-conservative, nonlinear, three-wave interaction, in which the growing pump wave decays into two damped daughter waves, has been shown to exhibit spatiotemporal chaos [1]. In the case of the Langmuir decay, when the pump wave has the largest group velocity, the pump wave saturates at a finite amplitude with the correlation function having definite length and time scales beyond which there is spatiotemporal chaos. The pump wave acquires a finite bandwidth in frequency and wavenumbers due to spatiotemporal chaos. Numerical simulations of the Langmuir decay show that the space-time profiles of the pump wave and the daughter waves are drifting coherent structures that evolve chaotically in time.

If the electron plasma wave (EPW) excited in stimulated Raman scattering is assumed to be the pump wave in the three-wave interaction discussed above, then the saturation of this EPW due to Langmuir decay will result in a saturation of the backscattered electromagnetic wave. The growth rate of the EPW depends on the density of the plasma while the Langmuir decay process can take place only when the amplitude of the EPW exceeds a threshold value. The saturated level of the backscattered wave will depend on the saturated level of the EPW. This may help explain the experimentally observed saturated levels of the backscattered light in laser-plasma interactions.

This work is supported by Lawrence Livermore National Laboratory Subcontract No. B-160456 and National Science Foundation Grant No. ECS-88-22475.

[1] C. Chow, A. Bers, and A. K. Ram, to appear in *Physical Review Letters* (June, 1992).

EXCITATION OF STIMULATED RAMAN SCATTERING IN LASER HOT SPOTS AND ITS NONLINEAR SATURATION

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The ponderomotive and thermal pressures induced by the localized high frequency fields in laser hot spots, including those from a random phase plate beam [1], can easily induce local flat regions in the electron density which provide loci for finite amplitude filamentation and absolute SRS instability. If the reflectivity (per unit solid angle per unit frequency) is known (or measured) for a given laser intensity then the linear response of the amplitude of the daughter Langmuir wave (LW), to the beat ponderomotive force of the incident and scatterd light, can be estimated. Even for very small reflectivities this amplitude is well above the damping threshold for the decay of the daughter LW into a secondary LW and an ion acoustic wave. This decay threshold is well below the amplitude for wave-breaking and above the amplitudes assumed in the theory of enhanced Thomson scattering [2]. This motivates a study of the saturation of SRS resulting from the turbulence induced by a LW cascade. Such cascade turbulence has been shown [3] to lead to a state of strong Langmuir turbulence which accesses the powerful dissipation associated with collapse. This model of saturated SRS in finite regions will be compared to experiments which indicate that SRS acts like a saturated, absolute instability whose threshold is controlled by damping and a recent hypothesis [4] that the amplitude of the SRS daughter LW saturates near the damping threshold for its decay instability.

[1] H. A. Rose and D. F. DuBois, poster this meeting.

[2] A. Simon and R. Short, PRL **53**, 1912 (1984).

[3] D. F. DuBois, H. A. Rose and D. Russell, PRL **66**, 1970 (1991).

[4] R. P. Drake and S. M. Batha, Phys. Fl. B**11**, 2936 (1991).

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SATURATION OF STIMULATED RAMAN SCATTERING BY THE EXCITATION OF LANGMUIR TURBULENCE

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Spectral simulations (in 1 dimension) of a model [1] of a SRS coupled to Langmuir turbulence have been carried out for regions of localized pump intensity modeling a laser hot spot. The self-consistent depletion of the electron density due to the ponderomotive force of the localized light and Langmuir fields are taken into account. The coupling [1] to SBS is neglected. The calculated reflectivity, R(t), is a highly intermittent function of time. The time averaged reflectivity, ⟨R⟩, increases somewhat faster than L^2 where L is the length of the hot spot. The saturation of ⟨R⟩ with increasing laser intensity, I_o, is more dramatic for larger L. Noncollisional dissipation of energy from caviton collapse, which produces hot electrons, increases faster with I_o than does the reflected light energy. A consistent nonlinear calculation is carried out of the "daughter" part of the Langmuir electric field, E_1 (x,t), which couples directly to the scattered light. The local value of the time average, $\langle|E_1|^2\rangle$, is found to be a function only of the modulus of the <u>local</u> light wave beat ponderomotive source which drives the Langmuir waves. This function depends only weakly on I_o and L. The saturated level of $\langle|E_1|^2\rangle$ increases slowly with driving strength and may attain levels considerably larger than the damping threshold for Langmuir decay. Because of nonlocal effects on the propagation of the backscattered light, the reflectivity from a single hot spot is not found to scale in the manner proposed by Drake and Batha [2].

[1] H. A. Rose, D. F. DuBois and B. Bezzerides, PRL **58**, 2547 (1987).

[2] R. P. Drake and S. M. Batha, Phys. Fl. **B11**, 2936 (1991).

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SIGNATURES OF CAVITON COLLAPSE OBSERVED IN RF MODIFICATION OF THE IONOSPHERE

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The nonlinear properties of the Langmuir turbulence excited by the parametric decay (PDI) and modulational instabilities near critical density by powerful RF waves in the ionosphere have been intensively studied by experiment and theory. Certain unique signatures of caviton collapse have been predicted and recently observed in the Thomson scatter spectrum. These include [1], the caviton continuum, the free mode feature in the plasma line spectrum and the enhanced zero frequency component of the ion line spectrum [2]. Recent spatially resolved observations [3,4] at Arecibo show that the turbulence lies in rather narrow horizontal layers which coincide with the standing wave (modified Airy) maxima of the pump wave. Altitude resolved power spectra [4] identified with a Langmuir decay cascade are consistent with the notion that the electron density profile is modified by the averaged ponderomotive force of the local layers of turbulence.

The Langmuir turbulence excited by Langmuir decay cascades resulting from the PDI, $2\omega_{pe}$ and SRS instabilities in laser-plasma interactions appears to have many properties in common with that of the ionosphere experiments. The later can be regarded as a test of some theoretical concepts applicable to laser-plasma interactions.

[1] D. F. DuBois, H. A. Rose and D. Russell, PRL **61**, 2209 (1988); Cheung et al. PRL **62**, 2676 (1989).

[2] DuBois et al., PRL **60**, 1970 (1991).

[3] Djuth et al., GRL **17**, 1893 (1990).

[4] Fejer et al., JGR **96**, 15985 (1991).

**Research supported by USDOE.

*Parametric Instability Driven by a Random Phase Plate Laser Beam

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The intensity of the laser field in the region near the best focus consists of speckles with characteristic width $f\lambda_0$, length $8f^2\lambda_0$, and intensity three times the average. This region exists over an axial length $2Nf^2\lambda_0$ on either side of the focal plane where N^2 is the number of phase plate elements in a square array, f is the f-number, and λ_0 is the laser wavelength. Assuming the instabilities in the individual speckles are independent of each other, we estimate the effect of RPP beams on SRS and SBS. Multidimensional simulations will be compared to these estimates.

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Radial Thermal Transport Experiments in Laser-produced Exploding-foil plasmas*

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A novel experimental technique for observing a propagating thermal heat front in a laser-produced plasma will be presented. The experiments use time-resolved, 2-D images of x-ray emission from thin, laser-irradiated titanium foils. The foils are irradiated with several beams of 0.35 μm light at a total intensity of ~ 1 x 10^{15} W/cm^2 in a ~ 1 mm spot. The plasma conditions in the heated region are electron densities ≤ 10^{22} cm^{-3} and an electron temperature of ~ 3 keV. X-ray emission that is characteristic of the thermal heat front is observed to propagate radially outward from the heated region. Comparison of these measurements with 2-D hydrodynamic simulations of the experiment suggests that the radial heat flux is much less than 10% of the free-streaming heat flux. The possible role of magnetic fields, ion-acoustic turbulence, and nonlocal heat transport will be discussed for the conditions of this experiment.

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Large Bandwidth Frequency-Converted Nd:Glass Laser at 527 nm with $\Delta\nu/\nu = 2\%$

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We report an experiment which demonstrates the efficient generation of large bandwidth, $\Delta\nu/\nu = 2\%$, in a frequency-doubled Nd:Glass laser at 527 nm, using a configuration suitable for use in ultraviolet laser fusion experiments. The technique uses the excitation of stimulated rotational Raman scattering in atmospheric pressure nitrogen gas in the focus of a large f-number lens. Its use in a large fusion laser would involve the use of a multilens array to produce multiple foci where the broadband conversion takes place. Our experiment simulated one element of such an array, at scale. The multilens array is fully compatible with the architecture of laser drivers for inertial confinement fusion experiments, both present and future. The multiline spectrum appears in about 250 ps and is as tightly focussable as the input beam prior to Raman conversion. This technique is also effective for frequency tripled or quadrupled lasers at 351 nm or 263 nm. It is well-suited to the suppression of plasma instabilities in ultraviolet laser fusion experiments.

REVIEW TALK I

R.S. Craxton, Chair

Monday July 13

Cryogenic Target Experiments with GEKKO XII 8 kJ, 527 nm Laser System

K.A. Tanaka

Cryogenic Target Experiments with GEKKO XII 8 kJ, 527 nm laser system

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Various cryogenic targets have been tested and used for planar and spherical geometry experiments using the second harmonic of the GEKKO XII Nd:glass laser system at ILE. Targets were cryogenic deuterium sustained in a light plastic foam (CDF) planes or shells, or cryogenic deuterium sustained in plastic shells, all prepared at the experimental chamber. Laser energy deliverable with random phase plates (RPP) is 8 kJ with twelve beams for the spherical implosion or 1.4 kJ with two beams for the planar target experiment with normally 1 nsec Gaussian or 1.8 nsec two stacked Gaussian pulse.
Laser light absorption in deuterium plasmas is 40-50 % at I_L=$3x10^{14}$ W/cm^2, believed to be mostly due to classical absorption. Backscattered temporally resolved spectra show no sign of stimulated Brillouin scattering, but only Doppler shifts. Among the corona nonlinear instabilities, two plasmon decay instability appears to be responsible for hot electrons of ~ 15 keV temperature. Shock temperature and speeds in CDF plane targets were measured under the effect of hot electrons and were compared with the hydrodynamic simulation code HISHO results. The ablation pressure of 20 Mbar was obtained at I_L=$3.4x10^{14}$ W/cm^2. The implosion showed preeimission at the center of the target about 200 psec prior to the time predicted by the code. In the implosion experiment using plastic shells with cryogenic deuterium layer corresponding to up to 100 atmospheres of the room temp. gas, neutrons of $2x10^7$ and ρR of 10 mg/cm^2 were measured.

MIXED POSTER SESSION I

Monday July 13

DEVELOPMENT OF A NON-LTE SPECTRAL POST-PROCESSOR FOR DENSE PLASMA SIMULATIONS WITH APPLICATION TO SPECTROSCOPIC DIAGNOSTICS IN SPHERICAL IMPLOSIONS AT NOVA

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A new non-LTE spectroscopy post-processing package is described. The package processes dump files from 1 or 2 dimensional radiation-hydrodynamics code simulations. Given the grid motion, temperatures, and ion densities contained in the dump files, as well as data from an arbitrarily detailed atomic model, the post-processor calculates internally consistent detailed frequency dependent opacities and radiation field. The radiation transport equation is solved in the S_n approximation using lambda iteration. Sub-cycling is used to achieve a more accurate solution to both the kinetics and radiation field calculations. Line broadening is included using Voigt widths based on the atomic rate coefficients, and Stark widths are included for K-shell spectra. The Sobolev escape factor approximation is available as an option.

This post-processing package has been used to analyze spectra obtained recently at Nova with Ar doped deuterium filled capsules. The dopant was designed to be primarily a density diagnostic (via Stark broadening) but can also be used for temperature diagnosis as well. Using a 300 level detailed model for argon, the package was used to simulate the observed experimental spectra. Differences between simulations and experimental data are investigated. Important issues affecting the results include radiation transport effects, pusher opacities, and continuum lowering. These results are compared to other simulation codes.

Analysis of Time-Integrated and Time-Resolved Capsule Symmetry Experiments on Nova

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Recent Nova hohlraum experiments have used x-ray imaging techniques to study the sensitivity of capsule implosion symmetry to changes in the experimental conditions.[1] These experiments used both 1 ns flattop and shaped pulses. The first part of this paper compares capsule performance data against LASNEX capsule simulations to establish the correlation between capsule performance and image distortion.

In addition to these "time integrated" measurements, we have recently begun studying time resolved symmetry. In these "build-a-pulse" experiments, the duration of square laser pulses is varied from 450 psec to 1 ns to obtain the dependence of image distortion on pulse length. We compare and contrast these observations with predictions of the image distortion vs. pulse length from 2d LASNEX simulations. We also present semi-quantitative reconstruction of the time-dependent drive patterns required to produce the observed x-ray images in 2d LASNEX capsule simulations. Finally, we compare our predictions of these capsules' performance with our observations.

1 D.B. Ress, A.A Hauer, L.V. Powers, R. Watt and R.E. Turner, "Implosion-Symmetry Experiments in Nova Hohlraums", to be published in *1991 LLNL Laser Program Annual Report.*

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Spatial dependence of x-ray conversion efficiency in laser-driven plasmas

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Abstract:

Data from experiments to investigate the spatial dependence of laser to x-ray conversion efficiency in laser-heated plasmas will be presented. Early results show unusual structures in time resolved x-ray images of plasma blowoff. These plasma profiles also show the spatial dependence of x-ray emission for three different photon energies (500 eV, 1.0 keV and ≥ 2.2 keV). It is observed that while the 500 eV emissions originate mostly near the solid and relatively cold material, the harder (≥ 2.2 keV) are generated both in the cooler and hotter regions of the corona. The data also suggest enhanced spreading of the laser spot when longer laser pulsewidth are used. The studies were done at the Nova laser facility, Lawrence Livermore National Laboratory, using single 1 ns, 0.35 µm laser beam on both high Z an low Z targets. Targets were viewed both face on and edge on. Laser intensity varied between $5x10^{14}$ and $2x10^{15}$ W/cm^2. Data were taken using a newly developed soft x-ray framing camera with a 100 ps temporal and 10 µm spatial resolution, respectively.

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Early Time Effects in X-ray Production from Laser-Irradiated High Z Plasmas

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Abstract

Many studies have investigated x-ray conversion efficiency from laser-irradiation of high Z targets. For short wavelength long pulse irradiations time integrated x-ray production from high Z targets is well modeled for intensities less than ~10^{15} W/cm^2. For shorter pulses of ~100 ps and early times during a longer pulse irradiation x-ray production is much lower than predicted using standard modeling used for longer pulses. We have begun experiments investigating effects of x-ray production at early times. We have used a new soft x-ray framing camera to image the thermal smoothing at early times. Significant structure is observed in the soft x-ray production due to structure in the beam which is significantly smoothed after about 500 ps. We have also begun investigating the ablation of medium and high Z materials at high powers to study the early time interaction of high powered laser pulses with the material. Comparison of the burnthrough times of Ni-coated Au targets will be presented.

Time- and Space-Resolved Density and Temperature Profiles from Aluminum K-shell Spectra

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We report on time- and space-resolved measurements of the plasma electron density and temperature in cylindrical Al cavities transversely irradiated through an off-center longitudinal slit as compared to slab targets.

The aluminum targets were irradiated with 100 ps/1054 nm laser pulses, point focused to 10^{14} W/cm^2. The K-shell radiation emitted along the slab surface or the cavity axis was dispersed onto the 18 mm-diameter CsI photocathode of the x-ray streak camera by means of a flat PET crystal in such a way that the dispersion direction coincided with the sweep direction. A 10 μm-wide slit between the PET crystal and the target provided the spatial resolution and a magnification of 30x. Time- and space-resolved electron temperatures and densities were determined from the H_α/He_α and I/He_α line ratios, respectively. To avoid opacity problems we have chosen a "sandwich" target design made of carbon with Al foils of thicknesses up to 25 μm. Typical cooling rates of about 10^{12} eV/s were obtained for a peak electron temperature of about 500 eV and peak electron density of about 10^{21} cm^{-3}.

The performance characteristics of the Kentech soft x-ray streak camera and the proximity image intensifier (VARO 9732) were characterized separately and the results from these experiments are presented. A carbon slab was irradiated by 1054 nm laser pulses, line focused to 4 mm x 100 μm, with pulse durations and corresponding maximum intensities between 50 ps/ $2 \cdot 10^{13}$ W/cm^2 and 700 ps/ $5 \cdot 10^{12}$ W/cm^2. Using a soft x-ray grating the bright H_α line at 18.2 nm was attenuated along a copper step wedge deposited on a 100 nm-thick Formvar foil in front of the 20 mm x 0.5 mm photocathode. For x-ray pulse durations between 350 ps and 2 ns the dynamic range was found to vary between about 50 and 300. Limitations in dynamic range can be attributed to longitudinal space charge effects. The dynamic behaviour and gain profile of the image intensifier were determined separately under uniform illumination of the photocathode. The output distribution was recorded by a cooled CCD camera (Photometrics STAR I).

Spectroscopic Electron-Temperature Diagnosis of Optically Thick Exploding-Foil Plasma in the Presence of an Intense Radiation Field

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The local electron temperature of a laser-produced plasma can generally be determined experimentally from the radio of two suitably chosen spectral lines from a spatially confined impurity dopant. When an intense, high-energy radiation field is present, photoexcitation effects can become dominant with respect to collisional excitation, making it difficult if not impossible to obtain electron temperature information from the spectral data. However, spectral methods may still be useful at relatively high density (about 1/10 critical) where alternative diagnostics such as Thomson scattering are not available. In this case, spectral lines which are least affected by the radiation field tend to be optically thick. We are using computer models to study these effects and to design an experiment to measure electron temperature by using spectral line intensity ratios in the optically thick limit.

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The Effects of Radiation Transport on Line Ratios used as Temperature and Density Diagnostics

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The ability to diagnose the conditions in the fuel of an ICF capsule is a fundamental requirement for progress in ICF. Current ICF experiments are concentrating on high convergence capsules, and capsules will be larger on the more powerful lasers that are currently under development. Both of these developments make it harder to diagnose fuel conditions because of the larger column density in the target. This has led to increased interest in the use of line ratios as temperature and density diagnostics. For a line ratio to be a good temperature diagnostic, the ratio must be relatively insensitive to density and vary strongly with temperature. Given the atomic rates, it is relatively easy to find candidate line ratios in the coronal limit where all lines are optically thin.

In this paper, we consider the effects of optical depth on line ratios. We show that, even if both of the lines used in the ratio are optically thin, the line ratio can depend on optical depth effects if one of the levels involved in the line ratio is pumped by an optically thick line. We present results from several different radiation transport models and attempt to draw conclusions about whether it is possible to calculate the effects of optical depth accurately enough that line ratios can still be used as diagnostics. We also consider the effects of uncertainties in atomic rates on predicted line ratios.

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.

Observation of Modulational instability in Nd-laser Beat-Wave Experiments

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We observe intense electron and ion waves generated by modulational instability in Nd-laser beat-wave experiments.

First high-intensity electron plasma waves are generated by the beating between a Nd-YAG (λ = 1.064 μm) and a Nd-YLF (λ = 1.053 μm) laser in a D_2 plasma. These waves are unstable with respect to the coupling with ions and decay into electron and ion waves which we can detect by Thomson scattering.

We discuss the importance of modulational instability in present and future beat-wave experiments.

PARTICLE ACCELERATION IN A RELATIVISTIC WAVE IN THE ADIABATIC REGIME

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The adiabatic theory of particle acceleration in a relativistic longitudinal plasma wave of fixed phase velocity is developped. The trapping condition for low energy particle is found to be more severe than the trapping condition previously obtained for a constant amplitude wave. Intermediate energy particles which are trapped in the wave experience the beam splitting and the beam heating effects, most of the particles ending in the larger energy beam. The particles which are not trapped experience no acceleration at all in the adiabatic limit. The validity conditions of the adiabatic theory are given for trapped and untrapped particles. Numerical results corresponding to the UCLA beat wave experiment [R.L. Williams, C.E. Clayton, C. Joshi, T. Katsouleas, and W.B. Mori, Laser Part. Beams **8**, 427 (1990)] illustrate the theory. They show the important role of the trapping condition.

The Group Velocity of Large Amplitude Electromagnetic Waves

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The nonlinear group velocity of a short intense laser pulse propagating in a cold underdense plasma is examined. The group velocity is defined in terms of energy transport and analytical expressions are obtained in the long pulse limit. These expressions reduce to the usual $\partial\omega/\partial k$ form for small amplitude and large amplitude group velocities are verified using PIC simulations. Short pulse group velocities, which are relevant to the Laser Wakefield Accelerator, are examined through numerical solutions to the nonlinear wave equation and with PIC simulations. Furthermore we find that short pulses have lower group velocities than long pulses. The relationship between laser pulse group velocity and wakefield phase velocity is also discussed. Techniques to control the wakes phase velocity are being investigated.

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Wake-field effect induced by a short laser-pulse in a plasma : limits of the plasma wave amplitude

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The usual approximation $v_g = c$ which underlies the theoretical works [1] on wake field effect (v_g denotes the laser group velocity and c the light velocity in vacuum) has been removed in order to tackle with the propagation of a laser pulse in plasmas with density not too far from the critical density n_c associated to the laser wave. An equation describing the electron plasma wave (EPW) potential and generalizing the previous works has been obtained and solved analytically and numerically. The inequality $v_g < c$ lets appear a limit for the EPW field to be reached : that corresponds to a wave-breaking condition accessible for a finite laser irradiance. The impact of this constraint on the EPW electric field pattern is discussed.

Using conditions far from the wave-breaking conditions mentionned above, PIC relativistic simulations (performed with the 1 1/2 D Euterpe code) have revealed a spatially damped EPW profile when moving away from the laser pulse region. The physical origin is an edge effect : electrons which exit the plasma through the interface plasma/vacuum the laser light penetrates undergo the laser pondermotive force in vacuum and go back inside the plasma out of phase of the collective electron motion. A trapping effect can result which absorb a large part of the initial EPW energy, so restricting the intense wake-EPW to a small region behind the laser pulse. Both of these effects generate a large amount of fast electrons.

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

STIMULATED BRILLOUIN REFLECTIVITY IN SHORT PULSE EXPERIMENTS

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We compute analytically and numerically the instantaneous stimulated Brillouin scattering (SBS) reflectivity of a homogeneous underdense plasma slab in the case of short pulse experiments. We first restrict ourselves to the standard SBS decay instability regime and we account for the thermal noise emission and for the initial pulse propagation through the preformed plasma. We compute the time integrated reflectivity as a function of the incident laser flux, for a given set of plasma parameters, namely the plasma length L, temperature T and density n/n_c. We compare these theoretical results with recent measurements [1] of SBS from 10ps experiments. The measured reflectivity is found to be higher by several orders of magnitude in the regime of low laser fluxes as compared with the theoretical predictions. We then search for the origin of the suprathermal level of the ion sound wave fluctuations by investigating the effect upon SBS of the coupling of the SRS driven plasma waves to the ion sound waves by means of a Zakharov-Maxwell type numerical code.

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

Stimulated Brillouin and Raman back/forward scattering induced by a short laser pulse inside an homogeneous plasma

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This work has been triggered by the experimental program to be planned onto the CEA picosecond laser systems. Our results come from PIC simulations using the 1 1/2 dimensional relativistic and electromagnetic PIC code Euterpe. A large range of laser irradiances from 10^{14} to 10^{18} W/cm^2 has been chosen in a 100 λ_0 plasma length in order to pinpoint the various regimes, linear and nonlinear characterizing the time/space evolution of the daughter waves amplified by the two scattering processes. The nonlinearity set subdivide into : laser pump depletion, electrostatic decay of the EPW driven by Raman scattering, EPW conversion process induced by the ion-acoustic wave (Brillouin-driven one and electrostatic-decay-driven one), electron trapping and ion trapping. The scattering light rates in the back and forward directions are presented, the features of the fast electrons as well. Compared to the nanosecond experiments, the low electron temperature and the small laser pulse length induce important modifications.

Backscattered Radiation, Cooling and Focusing of Electron Beams using Intense Laser Fields*

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Recent technological advances have made possible compact terawatt lasers with high intensities ($> 10^{18}$ W/cm^2), modest energies (< 20 J) and short pulses (< 1 ps). These high intensities lead to a number of new phenomena: coherent harmonic generation, relativistic optical guiding, laser wakefield generation, continuous frequency upshifting of laser pulses, etc.[1] An electron beam interacting with a counterstreaming intense laser field may have several practical applications: The generation of coherent and incoherent backscattered harmonic radiation in the XUV regime, emittance reduction (laser–cooling), and transverse beam focusing. Coherent harmonic radiation may be generated from a plasma or an electron beam (i.e., a laser–pumped free electron laser) via stimulated backscattering.[2] This stimulated process will be suppressed if the electron beam is not sufficiently cold, however, incoherent harmonics may still be generated via laser–induced synchrotron radiation (nonlinear Thomson scattering). For a relativistic electron beam, this radiation is very short wavelength, due to the $4\gamma^2$ doppler decrease in the backscattered wavelength, and well collimated in the axial direction. This implies that laser–cooling of electron beams is possible, i.e., the normalized emittance decreases as the electrons incoherently radiate. This cooling may be quite dramatic, i.e., substantial reductions in emittance may be obtained on picosecond time scales. Furthermore, an intense laser field may be used to focus an electron beam when the transverse laser profile exhibits a minimum on axis.

*Supported by the Office of Naval Research and the Department of Energy.

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[2] E. Esarey and P. Sprangle, Phys. Rev. A 45, 5872 (1992); P. Sprangle and E. Esarey, Phys. Rev. Lett. 67, 2021 (1991).

*Interaction of Ultra-intense Light with Underdense Plasmas

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We simulate the interaction of an ultra-intense light beam with an underdense plasma. The light intensity is $I\lambda_0^2 \gtrsim 10^{18} \frac{\text{W–}\mu\text{m}^2}{\text{cm}^2}$ where I is the intensity and λ_0 the wavelength. Strong half-harmonic emission as well as very energetic electron heating is found. 2-D simulations emphasize ejection of plasma from the beam in accord with simple estimates. Possible consequences of relativistic self-focusing are discussed.

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THIRD HARMONIC GENERATION WITH ULTRA-HIGH INTENSITY LASER PULSES

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Abstract

Harmonic generation in a plasma has been recently investigated and identified as a promising candidate for a coherent light source at very short wavelength. When an intense, plane-polarized, laser pulse interacts with a plasma, the relativistic nonlinearities induce third-harmonic polarization. A phase-locked growth of a third harmonic wave can take place, but the difference between the nonlinear dispersion of the pump and driven waves leads to a rapid unlocking.

The efficiency of the conversion of power to high harmonics is dramatically sensitive to this mismatch. The harmonic wave does not grow; instead, there are amplitude oscillations at a saturated level, scaling with ω_p^2. Having identified this problem we demonstrate that, by modulating the density, linear growth can be accomplished with an efficiency scaling with ω_p^4 or $\omega_p^{8/3}$.

Relativistic Harmonic Generation in Underdense Plasmas

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Relativistic harmonic generation from underdense laser-plasma interactions is investigated. Expressions for the power conversion efficiency into forward going third and fifth harmonics are derived in various limits. The steady state harmonic content of nonlinear linearly polarized waves is calculated for both $\frac{\omega_p}{\omega_0} << 1$ and $\frac{\omega_p}{\omega_0} \cong 1$ for arbitrary values of the wave amplitude. For weak nonlinearities equations are derived which model the evolution of the third harmonic for arbitrary $\frac{\omega_p}{\omega_0}$. In the absence of damping or density gradients the third harmonics amplitude is found to oscillate between zero and twice the steady state value. Arguments are given for extending these results to arbitrary amplitude. We also show that the quasi-static equations lead to errors in both magnitude and sign when calculating the third harmonic. Supporting computer simulations are presented.

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

1P18

INCOHERENT HARMONIC EMISSION FROM STRONG ELECTROMAGNETIC WAVES IN PLASMAS

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ABSTRACT

This is a re-examination of the work of Sarachik and Schappert on higher-order or harmonic Thomson/Compton scattering, with a view to its evaluation as a useful diagnostic for the interaction of weakly relativistic laser with low density plasma. Some consideration is given to plasma effects not mentioned in the original single-electron model (electron plasma oscillation and pure-electron self-focusing effects). While relative power scattering measurement can still be made, these plasma effects seriously complicate or compromise any attempts to use the Doppler shift content of the single-electron harmonic scattering, although plasma oscillations of some sort may well be inferred.

*Propagation of a Spatially Incoherent Laser Beam in an Underdense Plasma

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A spatially incoherent light wave (such as produced by a Random Phase Plate) of frequency ω_0 is incident upon an underdense plasma, where typically, at the focal spot, the intensity pattern exhibits fine scale structure, caused by interference between different wave vectors in the incident wave.

Order-of-magnitude estimates indicate that the plasma temporally smoothes the fine-scale structure after the light wave propagates about 2000 wavelengths (if an ion acoustic density fluctuation of 1% of the background density is present in the plasma). The scenario is that the interfering "beamlets" of the incident beam interact with the ion acoustic density fluctuation to produce a phase shift in the beamlets. This phase shift in the beamlets alters the interference pattern, which then acts to enhance the ion acoustic density fluctuation. To describe the linearized response, Rytov's method is utilized. Initial results will be presented.

* 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.

Statistical Properties of Laser Hot Spots Produced by a Random Phase Plate

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ABSTRACT

It is commonly assumed that the intensity field produced by passing a laser beam through a random phase plate (RPP) has Gaussian statistics leading to an exponential probability distribution, $P(I) \sim \exp(-I/I_0)$, of intensity, I. We will show that when I is sampled exclusively in hot spots,

$$P_{hot}(I) \sim I \exp(-I/I_0),$$

and intense hot spots are much more likely than the Gaussian assumption naively implies. The detailed amplitude and phase variation of the laser field in the vicinity of an intense hot spot will also be presented and shown to be simply related to the intensity distribution at the RPP. This hot spot structure may be used as a starting point for the analysis of various plasma instabilities.

We will show that if filamentation is ignored and the following condition is satisfied by a hot spot intensity

$$\left[I_{hot}/\left(\text{Watts/cm}^2\right)\right]/(T/\text{eV}) > \frac{10^{12}}{\pi(\lambda/\mu m)(L/\mu m)}\left(\frac{n_c}{n_0 F}\right)^2,$$

where λ is the laser wavelength, L is the density scalelength and F is the f/# of the optics then a density flat spot is created by the ponderomotive force which may allow for (otherwise density gradient inhibited) absolutely unstable SRS.

If the average intensity, I_0 strongly satisfies the above inequality but $I_0 < I_{abs}$ where I_{abs} is the threshold for absolute instability in a hot spot, and if it is assumed that once $I_{hot} > I_{abs}$ the hot spot SRS reflectivity strongly saturates with I_{hot} then (ignoring filamentation) the hot spot contribution to the plasma reflectivity, R, varies with I_0 as

$$R \sim (I_{abs}/I_0)\exp\left(-(I_{abs}/I_0)\right).$$

Thus, even if SRS is locally saturated, R may vary rapidly with I_0.

Hot spots may also provide finite amplitude seeds for filamentation: if the hot spot radius, $F\lambda$, is large compared to the wavelength of the linearly most unstable filamentation mode based upon I_{hot} then a filament is formed which collapses supersonically.

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Quasilinear Diffusion of Photons In an ISI Beam.

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In the *wave-kinetic* theory of laser–plasma interactions developed by Tracy and Boozer,[1] the Hamiltonian nature of the ray equations can be exploited to great effect. We have applied Wigner function techniques Pioneered by McDonald, Kaufman,[2] and Boozer,[3] to derive an appropriate wave–kinetic representation of the standard paraxial model of complex laser beams, such as those produced by *Induced Spatial Incoherence* (ISI) or other optical smoothing techniques. Wave–kinetic formulations of laser plasma interactions have been employed by other investigators,[4] however our work seeks to fully exploit the Hamiltonian nature of this framework.

Using quasilinear theory we have deduced an analytic expression for the diffusion tensor which governs the motions of photons in a background of sound wave turbulence, driven by an ISI type beam. Diffusion of rays may play an important role in the supression of filamentation. In the sub–threshold regime sufficiently fast ray diffusion could inhibit the formation of coherent structures, thus raising the threshold for filamentation.

We have developed a computer code that simulates the propagation of rays through a background of sound turbulence, typical of that produced in the wake of a complex laser pulse. Results of our simulations will be presented.

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[3] Submitted to Phys. Fluids. B.
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Landau-Fluid Simulation of Laser Filamentation*

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The Landau-fluid model is a recently introduced fluid-moment closure scheme that is designed to include kinetic dissipative effects like Landau damping in fluid calculations.[1] The fluid-moment hierarchy is terminated by expressing higher-order moments as linear combinations of lower-order ones in Fourier transform space. An n-moment description leads to an n-pole approximation to the linear plasma susceptibility. We use the technique in the 3D code F3D constructed to study laser filamentation in underdense plasmas. We find that if the ion and electron thermal conductivities and specific heat ratios are chosen as appropriate functions of k the undriven system supports ion acoustic waves with the correct frequency and damping rate over the full range of ion and electron collisionality. The dispersion relation of the driven system is a fourth-order polynomial for frequencies much less than the pump frequency and describes both ponderomotive filamentation and thermal self-focussing. The topology of the dispersion diagram depends on the pump strength, but above the filamentation threshold the roots always correspond to a damped and a growing filament and two damped ion waves that are propagating or non-propagating depending on k. An analytic instability-threshold condition on the pump strength is derived, from which the relative importance of ponderomotive and thermal effects can be assessed. We have used the F3D code to study the competition of ponderomotive and thermally driven filamentation for parameters of current interest. Expressions for the linear susceptibilities in the presence of a finite-amplitude pump, valid over the full range of ion and electron collisionality, are also given, which should be useful for the interpretation of Thomson scattering diagnostic measurements.[2]

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

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[2] M. Tracy, private communication, 1992.

EFFECT OF BEAM SMOOTHING ON FILAMENTATION*

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We have been using our 3-D filamentation code to study the effect of beam smoothing techniques on filamentation instabilities for parameters of current experiments.[1] Our simulations agree with the analytic result[2] that ponderomotive filamentation is stabilized when

$$\frac{1}{f^2} \gtrsim \frac{n}{2n_c} \cdot \frac{\overline{v_0^2}}{v_e^2}$$

where f is the f-number associated with the incident laser beam. This may be understood as a specific case of the general consideration that both ponderomotive and thermal filamentation are stabilized when the speckle length characteristic of the beam smoothing method is smaller than the filamentation spatial growth length. This stabilization is a key feature of our simulation results.

1. J. D. Moody, *et al.*, Random Phase Plate Effects on SBS Emission from NOVA Exploding Foils, Abstract submitted to this Conference.

2. A. B. Langdon, Laser Program Annual Report-1983, UCRL 50021-83 (1984), p 3-35.

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Studies of thermal filamentation with nonlocal thermal conductivity*

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Abstract

Thermal filamentation and self-focusing of laser light has been shown to be significantly altered in typical ICF type laser plasmas because of heat flux inhibition associated with nonlocal electron thermal conduction[1]. The conductivity becomes appreciably nonlocal when the electron mean free path is larger than about 1/100th of the temperature scale length. In contrast to previous flux-limiter models[2], this mechanism is also important for small temperature perturbations, such as those associated with thermal filamentation, where the heat flux can be orders of magnitude less than the free streaming value. Perturbation analyses show that this modified non-local thermal filamentation results in larger growth rates for small scale filaments, and instability in regions of the wavenumber spectrum that were previously stable.

Using our 3-D laser-plasma propagation code[3] modified to include a simple model of the nonlocal thermal conductivity[4], we investigate the scaling and behavior of non-local thermal filamentation. These simulation results are presented and contrasted with earlier results. Limitations of the modeling and implications for short-laser-wavelength ICF plasmas are discussed.

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2. R. C. Malone, R. L. McCrory, and R. L. Morse, Phys. Rev. Lett **34**, 721 (1975); W. L. Kruer, Comments Plasma Phys. **5**, 69 (1979).
3. A. J. Schmitt, Phys. Fluids **B3**, 186 (1991).
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Nonlocal heat transport in spherical plasmas using the Fokker-Planck code SPARK

by

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&

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The Fokker-Planck code SPARK is used to study nonlocal transport in a spherical CH or Au plasma under an assortment of physical scenarios. Energy is deposited into a thin outer region in the form of a trapezoidal pulse of duration 1.2 nsec (with 100 psec ramp-up) at a rate of 12.5 TW to give an effective source termperature of nearly 7 keV in a 0.1 n_c plasma at 0.35 μm irradiation. A hypothetical ICF capsule surface is simulated by prescribed inner surface boundary conditions which are chosen to bracket the possible transport conditions. The first boundary condition is a fixed temperature constraint which provides a measure of the maximum amount of energy deposited into a capsule by electron thermal conduction alone. The second condition is a zero heat flux constraint which allows for the maximum amount of thermal energy deposited just outside the capsule. The fixed temperature constraint is found to lead to a breakdown of the diffusive approximation to the Fokker-Planck equation by imposing a strongly non-equilibrium feature on the electron distribution function. By contrast, the zero flux condition relaxes the distribution function in a manner consistent with the diffusive approximation. In both cases, significant levels of early-time suprathermal electron energy flux and flux inhibition at intermediate times are indicated. Comparison with flux-limited classical transport is made and suggested remedies for the failure of the diffusive approximation in a strongly driven system are provided.

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ORAL SESSION II

D.D. Meyerhofer, Chair

Tuesday July 14

ULTRASHORT PULSE INTERACTIONS I

X-ray emission from a femtosecond laser-produced plasmas

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With recently developed high intensity lasers emitting subpicosecond pulses it is possible to create high energy density plasmas which can be used for the generation of sub-picosecond x-ray pulses. The availability of such x-ray bursts will have significant impact in many areas of plasma and solid state physics requiring time-resolved measurements. We will present recent experiments dealing with x-ray emission, x-ray spectroscopy, reflectivity measurements, energy transport.

Our laser system delivers an optical pulses of 100 fs duration at 620 nm with a maximum irradiance of 10^{17} W/cm^2 on the targets. In all experiments we monitor carefully the energy and the position of the amplified spontaneous emission (ASE), the intensity of which is 10^{-7} the main pulse intensity. For each shot the specular reflection and the scattered light are imaged on a CCD camera and the corresponding energies are recorded on diodes. An independant beam of 30 fs duration at a different wavelength is used as a probe beam in the optical diagnostics. A shadowgraphy technique using an imaging lens allows to obtain the time-resolved expansion of the plasma. Time-integrated X-ray emission spectra in the region 1.5 - 2 KeV are recorded with a high resolution Von Hamos spectrograph. A fast streak camera, with 2ps resolution, is used to measure the duration of the emission above 1 KeV.

Results will be presented for a variety of solid targets and for different laser conditions. The energy penetration inside the targets has been studied with layered targets and was found to be of the order of 1000 Å, significantly larger than the skin depth associated with the laser. A detailed analysis of Kα line emission from different ion stages shows that the 5-10 keV electrons created during the interaction heat the bulk of the solid to a temperature of 15-20 eV. The X-ray emission shows a sharp optimum as a function of the ASE. The measurements of the specular reflection and the scattered light of the laser show a correlation with the x-ray measurement. The shadowgraphy measurements and the analysis of the X-ray spectra will be presented and discussed.

Femtosecond Dynamics of a High-Intensity Laser-Plasma Interaction

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Using a pump-probe configuration, we study the interaction of a 400-fs 1-TW laser pulse with a solid target. The evolution of the expansion velocity of the critical surface is measured with femtosecond temporal resolution. The results confirm those of an independent third-order autocorrelation measurement, namely, that the laser pulse had an intensity contrast ratio of better than 10^6. Thus, unlike interactions with either poor-contrast short-pulse lasers, or long-pulse lasers, an interesting regime was accessible, where the electron density scalelength remains much less than the laser wavelength for the duration of the laser pulse. The results also indicate that, when the average electron quiver energy ($mv_{os}^2/2$) becomes comparable to the electron thermal energy (kT_e), the ponderomotive pressure of the short-pulse pump laser ($\sim$ 100 MBar) significantly reduces the thermal expansion of the laser-plasma. One of the important implications of this study[1] has been that a thermonuclear fusion reaction may be ignited by the local compression of a fusion pellet by this mechanism.

[1]X. Liu, D. Umstadter, E. Gabl, T. Auguste, J. S. Coe, C.-Y. Chien, and G. Mourou, "Optical Studies of Picosecond-Laser-Produced Plasmas," *Bulletin of the American Physical Society*, **35**, 2076, (American Physical Society, New York, 1990); D. Umstadter, X. Liu, J.S. Coe, and C. Y. Chien, "Density Profile Steepening by the Ponderomotive Force of an Intense Picosecond Laser," in *OSA Proceedings on Short Wavelength Coherent Radiation: Generation and Applications, 1991*, P. Bucksbaum and N. Ceglio, eds. (Optical Society of America, Washington, D.C., 1991), **11**, pp. 55-57.

MEASUREMENTS OF THE P-POLARIZED INTENSITY ENHANCEMENT IN HIGH-CONTRAST, PICOSECOND LASER-PRODUCED PLASMAS

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High-energy ion emission from high-contrast, picosecond laser solid interactions is used to determine the plasma scale length, electron velocity distribution, and the enhancement of the p-polarized electric field at the critical surface. A 1-μm laser with intensities up to 10^{16} W/cm^2 and an intensity contrast $>10^5$ is incident on solid Al targets. Al ions with energies up to 100 keV are observed. The ion velocity distribution indicates that nearly monoenergetic electrons are produced by ponderomotive acceleration in resonantly enhanced p-polarized laser electric field. The electrons have energies of 3–8 keV depending on the laser intensity. The electron energy is used to determine the enhancement of the p-polarized intensity at the critical surface with values of 10–100. The ion plasma scale length (~2000 Å) is inferred from the total ion number and an electron temperature of 100–500 eV is detected from the ion distribution. The intensity enhancement at the critical surface is found by solving Maxwell's equations with plasma wave dispersion effects and is approximately $(L_n/\lambda_0)^{4/3}$.[1,2] The enhancement is found to be consistent with the experimental results.

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K_α EMISSION FROM HIGH-CONTRAST, PICOSECOND LASER-PLASMA INTERACTIONS

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Strong K_α emission has been observed from the interaction of a high-contrast, p-polarized, 1-ps, 1-µm laser with an Al target at 10^{16} W/cm^2. The target consists of 6000 Å of Al coated on SiO_2. The K_α emission consists of three parts: strong Al K_α emission at a level comparable to the He-like line emission, comparable Si K_α emission, and relatively strong K_α emission from low-Z Al ions (shifted K_α). The relative amplitudes of the Si and Al K_α lines allow an estimate of the suprathermal electron energy distribution. Their absolute magnitude yields the total energy in the fast electrons. From this data the electron temperature profile in the overdense region can be determined and compared with that inferred from the shifted K_α intensities. A preliminary analysis suggests that the suprathermal electrons have 10-keV energies. This is consistent with the ponderomotive acceleration of the electrons in the resonantly enhanced laser field at the critical surface.[1] The distribution of low-Z Al ions may allow a determination of the thermal energy transport in the overdense region of the plasma.

1. S. Uchida, H. Chen, Y.-H. Chuang, J. A. Delettrez, and D. D. Meyerhofer, to be presented at the 22nd Annual Anomalous Absorption Conference, Lake Placid, NY, 12–17 July 1992.

This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under agreement No. DE-FC03-85DP40200 and by the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics, which is sponsored by the New York State Energy Research and Development Authority and the University of Rochester.

EFFECT OF THE PONDEROMOTIVE FORCE ON FAST IONS IN SHORT SCALE-LENGTH LASER-PLASMA INTERACTIONS

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Recent experiments[1] in which solid Al targets were illuminated by high-contrast, 1-ps, 1-μm laser pulses have shown the presence of a fast ion component with kinetic energies of about 100 keV. The strength of this fast ion component relative to the thermal component was strongly dependent on the intensity of the p-polarized component of the laser electric field. We present results of simulations with the hydrodynamic code *LILAC* in which the effects of the electron plasma wave is introduced into the wave equation[2] in two ways: with a Debye correction and by solving the coupled electromagnetic and electrostatic wave equations. The ponderomotive force resulting from the resonant field of the p-polarized component at the critical surface creates a cavity in the density profile and accelerates ions in the corona to the kinetic energies observed in the experiments. The pdV work done by the electromagnetic wave on the electrons leads to an increase in the laser light absorption fraction. Results and difficulties with the model are discussed.

S. Uchida, H. Chen, Y.-H. Chuang, J. A. Delettrez, and D. D. Meyerhofer, submitted to Phys. Rev. Lett.

2. J. A. Delettrez, P. Audebert, D. D. Meyerhofer, and S. Uchida, presented at the 21st Annual Anomalous Absorption Conference (Paper 2O6), Banff, Alberta, Canada, 14–19 April 1991.

This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under agreement No. DE-FC03-85DP40200 and by the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics, which is sponsored by the New York State Energy Research and Development Authority and the University of Rochester.

TIME RESOLVED keV SPECTROSCOPY OF ULTRASHORT PLASMAS

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We present time resolved X-ray spectroscopic studies (below 10 Å) of various targets irradiated with 400 fs pulses of 1.05 μm and 0.5 μm light with irradiances of 10^{16} W/cm^2. A commercial Kentech X-ray streak camera has been modified, following the route of Berkeley group[1], to obtain a 2 ps time resolution. Time resolution tests on direct keV X-ray emission, and obtained with a two beams system, will be presented. The camera has been coupled to a high resolution Von Hamos crystal spectrometer. Time resolved spectra (obtained in one shot) of ultra short plasmas will be discussed. The influence of the plasma density and gradient scale length on the X-ray pulse brightness and duration has been studied with double laser pulse experiments. Results will be discussed and perspectives will be outlined.

1. M. Murnane, Ph.D. Thesis, Univ. Cal. at Berkeley (1989).

Absorption of Intense Subpicosecond 1.06 μm Laser Light by Solid Targets

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Abstract

The absorption of intense subpicosecond 1.06 μm laser pulses obliquely incident on solid targets is measured. The 0.8 psec laser pulses are produced by a 10-TWglass laser system(1) and focused to a maximum intensity of 10^{18} W/cm^2 by an f/8 lens. The absorption is measured on high and low z target materials over the intensity range of 10^{16} W/cm^2 to 10^{18} W/cm^2. Backscatter, specular and diffuse light are collected separately.

The intense 1 psec pulse is expected to interact with a long scale length plasma (L_n/λ approximately 20) produced by a 400 psec prepulse with an intensity of approximately 2.5 10^{13} W/cm^2.

Preliminary correlations of the absorption with the production of hard x-rays will be given.

(1) F. G. Patterson and M. D. Perry, J. Opt. Soc. Am. B, Vol.8, No. 11, November 1991.

* 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.

Strongly Coupled Stimulated Raman Backscatter From Sub-picosecond Laser-Plasma Interactions

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and

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Abstract

We have observed strongly coupled stimulated Raman backscatter from the interaction of an intense (10^{18} W/cm^2), 0.8 psec laser with a uniform, underdense plasma. The strongly coupled backscatter spectra have widths greater than the plasma frequency, extend to the blue side of the laser frequency, and at the highest densities, are shifted by less than ω_p. These observations are consistent with the predictions of a strongly coupled Raman theory, appropriately modified for short laser pulses.

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.

Measurements of the Angular Distribution and Spectral Shape of the Hard X-Ray Emission From a 100 Femtosecond Laser Plasma.* D. Price, R. Shepherd, D. Gold, L. Van Woerkom, R. Walling, W. White, Lawrence Livermore National Laboratory--The observation of intense hard x-ray emission from ultrashort pulse plasmas has led to considerable speculation as to the production mechanism and conversion efficiencies involved. We present a study of hard x-ray emission utilizing ten channels of edge filtered PIN diodes to provide time integrated, spectral and angular emission information for various target material and incident polarizations. Measurements of reflected and scattered light at 1ω, 2ω, and 3/2ω are correlated to the observed x-ray emission. An intense hard x-ray spectra extending beyond 30 Kev is observed. The Intensity scaling and the influence of pre-pulse on hard x-ray generation is presented.

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

Fokker-Planck Simulations of Short Pulse Experiments.

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ABSTRACT

The recent development of short pulse lasers opens up an exciting new regime of Plasma Physics. Because of the short timescales, a large plasma corona does not have time to develop. Absorption takes place in a narrow skin layer which rapidly raises the temperature to hundreds of eV. The short timescale also prevents the penetration of the heat front into the target, leading to temperature scalelengths which are also sub-micron. These short density and temperature scalelengths are comparable to the thermal electron mean-free-path. Hence the heat flow is strongly non-Spitzer and the electron distribution function is strongly non-Maxwellian.

We have developed a one-dimensional Fokker-Planck code to model short pulse experiments. Results are presented and compared to a hydrocode using classical Spitzer thermal conductivity. The problem of modeling absorption correctly will be discussed and the effect of a prepulse on the plasma conditions will be addressed.

The interaction of ultra-short powerful laser pulse with solid target: ion expansion and a eleration.

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Abstract

The problem of ion expansion under action of powerful subpicosecond laser pulse on a solid target is considered firstly by means of ion kinetic equation. It is shown that the problem can be reduced to selfsimilar equations of quasihydrodynamic type in the case of growing in time the electron energy. The solution to this equation shows that the ion density profile appears to be much steeper than it is in the isothermal case. The reason for profile steepening is that the more energetic particles at the later moments of time can overtake the earlier and slower ones.

It is shown that maximal energy of accelerated ions is several times higher than it is in the isothermal case. At the laser flux density in excess of 10^{18} W/cm^2 the target can be the source of the fast ions with $E/z > 40 \cdot E_{os}$ (E_{os} - electrons oscillation energy) and with narrow energy distribution. As it follows from obtained solutions the ion expansion cannot change significantly the mode of laser interaction with overdense plasma. The values of ion energy and density scale for recent experimental parameters [1] are presented.

[1] T.D. Kmetec, C.L. Gordon III, T.T. Macklin, B.E. Lemoff, G.S. Brown and S.E. Harris, Phys.Rev. Lett.**68,** 1527-1530 (1992).

High-Intensity, Ultra-Short Pulse Laser Plasma Interactions*

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Since the recent advent of chirped pulse amplification of short laser pulses, there has been considerable experimental progress in the development of ultra-intense lasers (> 10^{17} W/ cm^2) , with the prospects of higher intensities (10^{20} W/cm^2) just ahead. Because of this rapid experimental progress, these lasers are quickly moving quickly into theoretically unexplored regimes of laser-matter interactions. One reason for this is that in this regime, the motion of electrons in the field of the laser is extremely relativistic and hence highly nonlinear, making theoretical progress difficult at best. We are using a relativistic, two-dimensional particle-in-cell (PIC) code (ZOHAR) to study the interaction of high-intensity lasers with steep gradient, vacuum-plasma interfaces. This simulation code allows us to investigate the nonlinear physical mechanisms behind the collisionless absorption of the light by the generation of hot electrons at the interface, as well as the propagation of these hot electrons into the dense plasma. Because the pressure of these lasers is so intense (> 10^3 Mbars), channeling of the laser far past the critical density is observed. In addition, we will present results predicting megaGauss DC magnetic fields in the overdense plasma, as well as very energetic ions produced at the interface that are directed into the overdense plasma. Finally, we will introduce a new method of harmonic generation that arises due to the relativistic motion of the electrons at the interface.

* 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 II

R.L. McCrory, Chair

Tuesday July 14

Non Local Transport in Laser Fusion Plasmas

E.A. Williams

*Non Local Transport in Laser Fusion Plasmas

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A quantitative understanding of electron thermal heat transport is critical to both the direct and indirect approaches to laser fusion. The incident laser energy cannot penetrate beyond the critical density. The laser energy absorbed in the low density corona is transported into the ablator or converter material by electron heat conduction. The temperature gradient developed in the plasma behind the critical surface is steeper than can be validly treated by classical hydrodynamic (Spitzer-Harm) theory which predicts unphysically large heat fluxes. The recognition that the classical theory fails when the scattering mean free path of a thermal electron exceeds approximately 1/400 of the scale length leads to the introduction of flux limits and later to non-local expressions for the heat flux. We review the genesis of these expressions from the more fundamental kinetic level and discuss recent results on the stability of these algorithms.

Non-local effects have been found to be important for the understanding of the thermal filamentation of laser beams. Even in a linearized theory, where the temperature perturbations are arbitrarily small, non-local effects inhibit lateral heat transport and de-stabilize filamentation. Because the theory is linearized, the effective k-dependent transport coefficients can be obtained from kinetic theory without the necessity for drastic simplification of the collision operators.

* 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 II

Tuesday July 14

Nonlinear Plasma Wave Excitation in the Microwave Range

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Experimental evidence is given of a new regime of the Zakharov equations, in which plasma waves, trapped in a density cavity at the top of a parabolic profile, exhibit an oscillatory behavior.

The excitation of plasma waves by resonant absorption of an electromagnetic wave is studied experimentally near the top of a parabolic density profile created in a multipolar device ($n_e \sim 10^{11} cm^{-3}$). The experiment shows the building of a huge density cavity ($2000\lambda_D$) inside which plasma waves are trapped. The plasma is expelled from the resonant region by the ponderomotive force associated with the plasma wave electric field. Then, the electronic density on the edge of the cavity becomes larger than the critical density. The cavity is then decoupled from the driver, the plasma wave is damped and the density on the edge becomes below critical. The cavity is pumped again by the electromagnetic wave and a new cycle starts, on a time scale smaller than the convection time.

The wavebreaking time of plasma waves in a cold plasma with a parabolic profile has been obtained analytically. The results are similar to those obtained in a linear profile except at the top of the parabolic density profile where the wave breaking time is shown to be proportional to E_d^{-1} instead of $E_d^{-1/2}$, E_d being the driving field. We show that, with the parameters of the experiment, wavebreaking is not responsible for the observed behavior of the plasma wave.

Finite Bandwidth Effects on Stimulated Brillouin Scattering in Inhomogeneous Plasmas

by

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Stimulated Brillouin Scattering (SBS) involves scattering of light waves off low frequency ion acoustic waves. Since the frequency of the acoustic wave is comparable to the present day bandwidths of the laser light, the W.K.B. approximation (in time) cannot be justified for the acoustic waves. Conventional results of bandwidth on parametric instabilities involving two coupled first order equations (p.d.e's) are not valid for S.B.S. We will present results for the study of the effects of bandwidth for S.B.S., without the use of W.K.B. approximations for the acoustic wave, in homogeneous as well as inhomogeneous plasmas.

TWO DIMENSIONAL SIMULATIONS OF STIMULATED BRILLOUIN SCATTERING AND FILAMENTATION INSTABILITY IN LASER PRODUCED PLASMAS

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(a) Department of Electrical Engineering
(b)Canadian Network for Space Research
(c) Department of Physics
(d) P. N. Lebedev Physics Institute, Moscow, Russia

The system of Maxwell equations and the linear wave equation for the acoustic modes coupled through the ponderomotive force are solved numerically in the *2D* cartesian geometry of finite extent. This model allows us to study simultaneously for the first time, the filamentation instability (FI) and the stimulated Brillouin scattering (SBS) by avoiding paraxial optics approximation.

The numerical method employs a Fourier Galerkin expansion in the perpendicular direction and a spectral Tau method involving an expansion in Chebyshev polynomials in the direction of laser pulse propagation. An implicit midpoint scheme in time is employed with iterative improvement of the nonlinear terms.

Our preliminary runs have shown strong growth of stimulated Brillouin scattering (SBS) with a maximum intensity of scattered light in the backward direction decreasing monotonously within wide angle and reaching minimum at the exactly sidescattered directions. Later in the run we observe equally strong signal of scattered light in the near forward direction which can be attributed to near forward SBS and/or filamentation instability (FI). Both instabilites belong to the same branch of the linear dispersion relation.

The range of parameters where SBS and FI can coexist and compete will be discussed. The formation of filaments in the presence of SBS will also be described.

NUMERICAL SIMULATION OF THE $2\omega_{pe}$ INSTABILITY

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and

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Results of the numerical simulation of the two-plasmon instability of a powerful electromagnetic wave are presented for parameters close to the experiments. The aim of the simulation is to study the basic features of the $\frac{3}{2}\omega$ radiation, which is known to be generated by the laser wave coupling with long-wave plasmons. Hence, to obtain the relevant information, the long-wave length part of plasmon spectra versus the plasma density and observation angle are studied. Particularly, it is shown that radiation takes place even for relatively low plasma densities down to Landau cut-off $(\omega_0 - \omega_{pe})/\omega_0 = 3(kr_D)^2 = 0.3$. It is also demonstrated that long-wave length plasmons are generated due to the modulational instability, which is an evidence of the inapplicability of weak turbulence theory in this situation.

Observation of SRS at λ_L=527nm with random phased plates

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In inertial confinement fusion, controlling preheat in the imploding shell is an important issue to achieve high temperature and high density states in the compressed fuel. Stimulated Raman scattering (SRS) could be considered as possible sources of preheat.
At ILE implosion experiments of cryogenic deuterium foam targets with ablator(CDFTA) have been performed which is composed of a plastic foam shell saturated with the deuterium fuel, coated with plastic. The best suited thickness of plastic ablator has not been determined yet. To determine the thickness of plastic for the suppression of SRS, we have observed SRS spectra using dry plastic foam shell coated with plastic same as CDFTA except the deuterium. The GEEKO XII 12 beam glass laser system has been used at 527 nm laser wavelength with random phase plates. The shape of the laser pulse was a flat top, with1.7 nsec FWHM at a laser intensity 3 x 10^{14} W/cm^2 . With a 1μm plastic overcoat, the time-resolved spectra of scattered light shows three different components in the convective SRS (C-SRS) growth region. A component generated in the latter half of laser duration was recognized as C-SRS for pure plastic shells. Second component, which is emitted around 1000 nm, may be same as the blue-shifted component of the light near $\omega_0/2$ observed by D.W.Phillion et al[1]. Third component, which was clearly SRS, was observed at an early time in the laser duration only when shooting the 1μm plastic overcoated foam shell. This SRS decreases its wavelength rapidly in time with narrow spectral width and the intensity was stronger compared with usual C-SRS. These features may be indicative of a flat electron density section in the overall expanding plasmas.

1. D.W.Phillion, D.L.Banner, E.M.Campbell, R.E.Turner, and K.G.Estabrook, Phys. Fluids **25(8)**, 1434 (1982)

The interpretation of Stimulated Raman Scattering from previous laser-produced plasma experiments

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We have investigated the effects of collisions on the stimulated Raman scattering (SRS) spectrum from the experiments of Shepard *et al.*[*Phys. Fluids* **29**, 583 (1986)] and Tarvin *et al.*[*Laser Part. Beams* **4**, 461 (1986)]. We calculated the convective gain including collisional effects and the distribution of laser intensities. We also used this distribution of laser intensities to calculate the fraction of the laser energy above the damping threshold for absolute instability, ignoring effects of inhomogeneity. For the experiment of Tarvin *et al.*, as for many previous experiments, a significant fraction of the laser spot is at intensities above the damping threshold for absolute instability, however, the convective gain is very small. In addition, the upper and lower cutoffs in the spectrum could possibly be determined by damping. In contrast, for the experiment of Shepard *et al.* we find that no part of the measured initial laser spot exceeds either the convective or the absolute damping threshold. Assuming that filamentation produced an amplification of the laser intensity, we discuss the convective gain and absolute thresholds that would result.

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Twenty-Second Annual Anomalous Absorption Conference
Lake Placid, New York
12–17 July, 1992

Random Phase Plate Effects on SBS Emission from Nova Two–Beam Exploding Foils*

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We have experimentally investigated the effect of random phase plate (RPP) beam smoothing on SBS backscattered light in exploding foil plasmas. The experiments consist of measuring the backscattered SBS emission excited by an unsmoothed and a RPP smoothed interaction beam impinging on a preformed plasma. A Ti or CH plasma is preformed with typically 2500 J of 0.527 μm RPP smoothed laser light with a square pulse duration of 1 ns. The interaction laser, which is focused to the center of the preformed plasma, has a pulse duration of 1 ns, 0.527 μm wavelength, approximately 2500 J total energy, and reaches the plasma after an adjustable delay time. The phase plate is composed of hexagonal elements, 7 mm in diameter, with a random distribution of cells that add a phase shift of π to the oncoming phase front. The backscattered light is imaged through a 1 meter spectrometer into a streak camera where a time resolved spectrum is recorded on photographic film. We measure at least a factor of 10 times less backscattered SBS energy with the use of a RPP. The backscattered emission shows some dependence on plasma composition and interaction beam delay time.

[1] *Permanent address: École Polytechnique, Palaiseau, France.*

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

A Multi-channel time resolved Thomson scattering diagnostic to investigate the Ion Acoustic decay Instability*

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and

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We have developed collective Thompson scattering diagnostics to measure plasma waves excited by the Ion Acoustic Decay Instability (IADI) in a (1.06 mm) laser produced plasma. Thompson scattering allows more detailed diagnosis of the IADI than has been possible in previous experiments using second-harmonic emission. The collection optics covered scattering angles of 93 to 133 degrees relative to an input probe beam at 3w using 5 channels. Fiber Optics transfer the signals to an optical spectrometer/streak camera system with wavelength resolution of 0.2 angstroms and time resolution of 250 ps. The Streak camera output is digitized with a CCD camera. We have measured the time resolved scattering from the ion acoustic waves excited by the IADI. A clear scattering signal is observed at the stokes side.

* This work is partially supported by the NLUF program at LLE, U of R, with support from the USDOE. The work performed at LLNL is partially supported by the Plasma Physics Research Institute, UCD and LLNL, and partially by the LLNL ICF Program. Some of this work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

Detailed 266nm Thomson Scattering Measurements of a Laser Heated Plasma.

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Collective Thomson scattering at 266nm is used to obtain spatially-resolved two-dimensional electron density, ion-acoustic sound speed, and radial drift profiles of a collisional laser plasma (critical density, $n_c = 1 \times 10^{21}$ cm^{-3}). The experimental results are compared with a hydrodynamic simulation LASNEX. Percent standard deviation agreements of 40% for the electron density and 50% for the ion-acoustic sound speed and radial drift velocities are obtained. Detailed measurements of this type are beneficial in validating existing models of laser-produced plasmas.

Under our conditions, the 266nm probe beam scatters off of collisional ion-acoustic waves ($k_{ia}\lambda_{ii} \approx 0.1$ and $k_{ia}\lambda_{ei} \approx 1$) to produce the Thomson spectrum. The heat transport drives a return current of thermal electrons and the resulting electron Landau damping is reduced(increased) for ion-acoustic waves traveling parallel(anti-parallel) to the drifting thermal electrons. Therefore, the spatially dependent heat transport can be inferred from peak height asymmetries in the Thomson spectra. Further investigations of this nature require line shape analysis of the Thomson spectra which for collisional waves is not well understood. Preliminary results of an analytic model valid for Thomson line shape analysis in this regime will also be presented.

1 M.D. Tracy is a Hertz/Lawrence Livermore National Laboratory Fellow and would like to acknowledge his financial support from the Fannie and John Hertz Foundation.

* Work performed under auspices DOE contract number W-7405-ENG-48.

*Kinetic and Hydrodynamic Simulations of Interpenetrating Laser-Produced Plasmas

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The level of interpenetration and stagnation of counter-streaming laser-produced plasmas, which is affected by both collective and collisional effects, is investigated via use of a kinetic and a hydrodynamic model. Each of these one-dimensional models can evolve multiple ion and/or electron species in a self-consistent electrostatic potential. The kinetic code[1] combines implicit particle-in-cell (PIC) and Monte Carlo (MC) Coulomb collision models into a single package. The hydrodynamic code[2] also employs implicit methods to advance the fluid species in time.

These codes are used to study the colliding plasmas generated by two C or CH laser-heated exploding foils which are aligned such that their normal vectors are co-linear. The hydrodynamic simulations are performed with either a single fluid for each of the species, or with a separate fluid per exploding foil for each of the species. The previous approach leads to stagnation when the two plasma streams meet, resulting in high ion temperatures and low ion densities at the stagnation point. In the latter approach, the streams interpenetrate and slow down as a result of electrostatic and collisional forces. The kinetic simulations employ separate species for each of the exploding foils.

The kinetic model is also used to investigate the growth and saturation of the ion-ion two stream instability in the inhomogeneous exploding-foil plasmas. Results of such simulations performed in both the collisionless and collisional limit will be presented.

* 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.

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[1]R. J. Procassini and C. K. Birdsall, *Phys. Fluids B3*, 1876 (1991)
[2]P. W. Rambo and J. Denavit, *J. Comp. Phys.* 98 317 (1992).

Kinetic simulation of a plasma collision experiment

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I present a one-dimensional numerical model of a recent experiment[1] involving the interpenetration of two medium-Z laser-produced plasmas facing each other.

Multifluid codes[2,3] are appropriate to describe the early, mildly collisional stage of such an experiment, when the ionic streams interpenetrate at high velocity. However, I developed a simple, semi-analytic model which yields qualitatively correct results in this stage without having to use such codes.

The subsequent strongly collisional stages of the experiment are modelled by an ionic Fokker-Planck code[4] which has been improved to accomodate the specific distribution functions encountered in this system.

[1] R. A. Bosch, R. L. Berger, B. H. Failor, N. D. Delamater, G. Charatis, R. L. Kauffman, Phys. Fluids B4, 979 (1991).

[2] P. W. Rambo, J. Denavit, J. Comput. Phys. **98**, 317 (1992).

[3] R. L. Berger, J. R. Albritton, C. J. Randall, E. A. Williams, W. L. Kruer, A. B. Langdon, C. J. Hanna, Phys. Fluids B**3**, 3 (1991).

[4] M. Casanova, O. Larroche, J.-P. Matte, Phys. Rev. Lett. **67**, 2143 (1991).

Simulations of High Density Colliding Plasma Slabs Using a Hybrid Particle-in-Cell Model with Interparticle Collisions*

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We have developed a interparticle collision model in the 2-1/2-dimensional hybrid version of our particle-in-cell computer model, ISIS. The electrons are treated as a massless fluid and the ion are treated as particles and the full set of Maxwell's equations is solved. The new model includes electron-ion and ion-ion collisions for an arbitrary number of species. The model is based on a method that ensures local momentum and energy conservation. We have applied this model to the conditions of recently published data for experiments performed at KMS.[1-3] In these experiments and similar experiments performed elsewhere[4], two laser beams are used to heat foils separated by a few hundred microns. The resulting plasmas collide and typically stagnate in the space between the foils. The ion mean free path is quite sensitive to the parameters in the experiment and can be comparable to the separation between the foils. Calculations will be presented which show the effects of collision rate on the stagnation process. Important physical effects neglected in a multifluid model of this phenomena will be discussed and the challenges in using a more fully kinetic model, such as the particle-in-cell method will be described. Also, the effects of electron energy transport on the stagnation process will be described.

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Numerical study of interpenetrating plasma streams using a 1D Eulerian multi-phase code

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A 1D multi-phase eulerian code similar to the U.S. one of [RAM,BER] is developed to study the interpenetration of two rapidly expanding laser-ablated plasmas [BOS].

The hydrodynamic model is derived from previous calculations performed by Spitzer and Braginskii and is extended to several ion fluids and one electron fluid [DEC]. The slowing down and thermalization of these plasmas are due to the Coulomb collisions between all the species (electrons and ions). As main assumptions of the physical model, we take : magnetic field and electric current set to zero, quasineutral approximations, electrons near equilibrium. At present time, the approximations for a simplified version of our model are : constant average ionization, perfect gas, two ion species almost identical. With our model, the electric field can be removed of the motion equations.

Our numerical scheme is among the class of Lagrangian-Projection type schemes.

The Lagrangian step is similar to a Von Neumann Richtmyer scheme. The ion velocities are calculated with a predictor-corrector scheme which is second-order accurate in time accounting for velocity dependance upon collision frequencies. The electron velocities are computed according to the zero current condition. The implicit calculation of both ion and electron temperatures takes into account the ions and electron heat conduction, the thermal exchange between the different species and thermalization of kinetic energy.

The projection method is second order accurate in space by appropriate slope limitations and includes material-vacuum boundary tracking (S.L.I.C). The densities, thermal energies and velocities of all species are remapped at each iteration on the Eulerian meshes by calculating the mass, thermal energy fluxes at cell boundaries and deplacement fluxes at cell centers.

As numerical experiment, we compare the results of our 1D Eulerian multi-phase code to those obtained by a 1D Lagrangian multi-material code.

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Fluid Equations for Interpenetrating Plasmas

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The description of the interpenetration of two plasmas rapidly expanding towards each other recently raised interest [1, 2, 3, 4]. We have set up a system of fluid equations for electrons and several ion species, with all slowing down and energy exchange terms in electron-ion and ion-ion collisions, and electronic transport coefficients (thermal and electrical conductivities, thermo-electric coefficient), and ionic thermal conductivity.

The main hypotheses are :

- Electronic thermal velocity is higher than any other velocity.
- Every ion species is near local thermodynamical equilibrium (wrong at the end of slowing down, when ion distribution functions overlap).
- Electrons are near local thermodynamical equilibrium (wrong in the dilute part of a hot corona).
- Total electric charge and current vanish (same remark ; only time and space scales larger than plasma frequency and Debye length will be considered).
- No turbulence.

A first slowing down phase (for Mach numbers larger than $(18\pi m_i/Z_i m_e)^{1/6} \simeq 8$) may be made by collisions of ions on electrons, with electron heating. Then ion-ion collisions dominate, with heating of ions, which slowly share their energy with electrons.

In the case of ion species with different charges, electrical resistivity can play a role in electron heating.

Atomic physics effects have not yet been considered.

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A search for gain in a Ni-like tin plasma

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Soft x-ray amplification in a collisionally excited Ne-like Ge plasma has been extensively studied in a number of laboratories. The success of these experiments has led us to search for a Ni-like analogue of the Ne-like system. Extensive simulations of our plasma conditions led to the choice of the Ni-like Sn system which was expected to have highest gain on a 4d-4p, J=0-1 transition at ~120 Å. The experiments were carried out with a Nd:glass laser system operating at 1.06 μm at intensities up to 1×10^{13} W/cm^2. The maximum length of the line focus plasma was 33 mm. Two flat field VUV spectrometers were used in the experiment. An axial spectrometer was aligned along the axis of the line focus and observed emission in the 40-120 Å region. An off-axis spectrometer, which recorded the M-shell emission in the 10-30 Å region, monitored the ionisation balance in the plasma. Simulations of our plasma conditions have indicated that trapping and refraction of the amplified emission would make it very difficult to observe gain with solid targets. However a gain of ~1 cm^{-1} may be expected with thin foil targets. Our most encouraging results have been obtained with single sided irradiation of a thin layer (~30 μgm/cm^2) of Sn deposited on a thin plastic film. Despite strong attenuation of an Ag foil (filtering the axial spectrometer), emission was observed on two 4d-4p Ni-like transitions at 118.9 and 114.5 Å.

Measuring the Ion Temperature in X-Ray Laser Plasmas

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One of the most important parameters for the characterization of x-ray lasers is the ion temperature (T_i) since it is related to the small signal gain through the Doppler broadening of the laser line. However, very few T_i measurements from x-ray laser plasmas are available at this time. We report the inferences of the ion temperature in neonlike germanium plasmas, as well as from plasmas with different Z, using both Thomson scattering and x-ray spectroscopic techniques.

Thermal Thomson scattering spectra characterized by $\alpha \equiv 1/(k\lambda_{De}) \geq 1$ and high $\beta \equiv [(Z\alpha^2 T_e)/(T_i(1+ \alpha^2))]^{1/2}$ show resonances at $\pm\ \omega_{ia}$ (the ion acoustic frequency). The separation of these peaks in the scattered light spectrum has been used to determine the electron temperature of x-ray plasmas. In addition, the ion temperature can be inferred from the shape of the resonance. This shape is characteristic of the mechanism responsible for the damping of the ion waves. For low Z plasmas (e.g. carbon), ion Landau damping is responsible for the observed width of the ion peaks. For higher Z plasmas like neonlike germanium, the collisional damping of the ion waves is dominant.

X-ray emission lines from an optically-thin, low density plasmas may be studied with high spectral resolving power; the Doppler broadening of the line shape can be used to deduce T_i . A plasma composed of different Z impurities (assumed in equilibrium) allows one to obtain a good estimate of the thermal Doppler effect. By introducing light ions (Na) in a germanium plasma, we were able to measure the ion temperature through the width of the Na Ly-$\alpha_{1,2}$ emission line. Within the experimental error bars, both methods agree and give $T_i \sim T_e \approx 400$ eV for the neonlike germanium plasma.

Modelling of the output beam in x-ray lasers.

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1. Abstract

We compare the predictions of our simulations of the x-ray laser output beam with recent experimental observations on collisionally pumped Neon like Germanium systems. The predictions of the output beam properties are obtained using a recently developed ray tracing program, which, in turn, relies on detailed hydrodynamic and ion kinetic modelling. We shall discuss both the results from the hydro-kinetic code (EHYBD) and the results from the raytrace code (RAYS). The time integrated beam characteristics are compared with results from recent exper-iments carried out at the Rutherford-Appleton Laboratory. We conclude that the good agreement we find between our predictions and the experimental results leads to greater confidence in our hydrodynamic modng.

The raytrace program was also used to model a double amplifier plus mirror configuration, designed to demonstrate the onset of gain saturation. The output from RAYS for the double target configuration was used to obtain predictions for the ratio of intensities of the 232 and 236 lines, $R_{6:2}$, as a function of gain length product. The calculated values for $R_{6:2}$ were in reasonable agreement with the experimentally measured values. This is an important result as it has been argued that the variation in this ratio can be used as an indication of the onset of gain saturation.

ABSTRACT

Methods for Increasing the Gain Coefficient of Short Wavelength Collisional X-Ray Lasers

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Although nickel-like x-ray lasers have been a success in recent years, the output of these lasers must be increased from microjoules to milijoules for most applications. We present several techniques to increase the gain including high intensity, beam smoothing and pulse shaping, and a new material LIHTA [$(LIH)_{.9}$ $(TA)_{.1}$], for which the ion and electron temperatures are decoupled.

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

Opacity Model Sensitivity of Diagnostic Witness Plates. J. K. Nash, R. J. Olness and S. P. Hatchett II, Lawrence Livermore National Laboratory.* — Apparent discrepancies in the LASNEX modeling of a number of ICF experimental observables (*e.g.* shock transit times and Rayleigh-Taylor instability growth rates) have given rise to questions concerning the state of knowledge of the x-ray absorption coefficients (*i.e.* opacities) for the materials used as ablators in these experiments. A modification to the standard XSN opacity model has been somewhat successful in resolving these discrepancies. Though physically motivated, this modified scheme incorporates such drastic approximations that an analysis founded on a more fundamentally-based opacity model seems appropriate. We report on the progress obtained in applying the OPAL benchmark opacity model to the case of shock transit times in side-by-side stepped witness plates (aluminum and glass). Excellent agreement is obtained with experimental data for the cases studied thus far. We will present results for the OPAL, XSN, and modified-XSN opacity models and discuss the influence of the theoretical differences on the hydrodynamical development of the ablation front.

*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.

ORAL SESSION III

C.E. Capjack, Chair

Wednesday July 15

HYDRODYNAMICS AND DIAGNOSTICS

Hybrid Direct/Indirect Drive Target*

S. V. Coggeshall

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A new ICF target design concept using a combination of direct and indirect drive will be discussed. The idea is to surround a nominally direct drive capsule with a spherical layer of protective material which is somewhat diffusive to radiation, but opaque to the laser light. At early times the laser strikes the outside of this material, generating a radiation wave felt by the capsule ablator. Early time ablation is radiatively driven, creating a uniform, warm corona around the capsule. This warm corona can eliminate the startup problem for direct drive.

Several goals in this design will be discussed. One requirement, in order to be energetically favorable, is that this diffusive medium must be ablated away sometime in the laser pulse before the main drive portion. In this way the capsule is directly driven for the bulk of the drive energy. A further consideration is to hydrodynamically decouple this outer region from the capsule as much as possible. The laser will imprint hydrodynamic perturbations on the surface of this protective medium, and these should be minimally coupled to the capsule.

The results shown here will be preliminary. Two 1-D designs will be discussed, one using a plastic foam doped with a high-Z material, the other using a thin plastic/high-Z balloon filled with He gas. Because of calculational difficulties with the foam design, the plastic balloon design will be discussed in more detail.

This design concept can be made to work well in 1-D, but the real tests are 2 and 3-D with realistic laser characteristics. It is expected that the long scalelength corona introduced by this design will cause small-angle laser refraction which could result in significant redistribution of the light at critical. Recent calculations show this to be the case, but the consequences are not yet known quantitatively. Significant flexibility exists in 1-D design parameter space which may allow the control of this effect, possibly to the enhancement of smoothing at later times.

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

A Numerical Investigation of NIKE Target Edge Effects

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Laser systems have finite intensity spots in the directions transverse to the propagation of the beam. Initially planar laser targets accelerated by such beams develop large transverse deformations at the edge of the high-intensity region of the illumination spot. To design laser-target experiments which maximize the laser energy available for target acceleration while minimizing edge effects it is necessary to investigate the finite-spot, planar laser target system by means of numerical simulation.

We here report results from our ongoing series of edge-effects hydrodynamics simulations in two-dimensional r, z geometry, where the beam emanates from $z = +\infty$ and is finite in radius r. Our parameters are chosen to match as closely as possible those of the NRL NIKE laser system now under construction, with laser intensities ranging from 1 to 3×10^{14} W/cm^2, energies of a few kilojoules, contrast ratios on the order of 300, and spot sizes of approximately 650 μm in diameter.

Our results indicate that planar laser targets are sensitive to sharp beam edge profiles. In the presence of a steep intensity fall-off (a "top-hat" profile) strong inward-directed flows quickly develop, inhibiting uniform planar acceleration in the region illuminated by the high-intensity part of the spot. A similar effect is observed in cases where a thick ring of plastic encircles the central laser-target region.

However, in cases where the intensity profile is allowed to fall off more gently, with a scale-length on the order of 100 μm or more, there is much less inteference of edge effects with the target bulk planar acceleration. The shear flow that develops in the edge region has a dominant outward radial component, and the target remains flat and accelerates uniformly in the flat central region of the laser spot.

Work supported by USDOE and ONR.

Increasing Xray Conversion Efficiency by Shifting the Power Balance

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M. Cray
Los Alamos National Laboratory

The point of this theoretical paper is that xray conversion efficiency is not just "one thing". It's not an unchanging monolith properly represented by 1ns disc experiments. Instead, it's a quantity which, in general, can be widely different in different situations. We show conversion efficiency to be a varying quantity which is sensitive to changes that end up modifying the overall power balance.

We argue this point with the results from a series of 1-D and 2-D LASNEX simulations. These simulations investigated conversion efficiency in number of very different situations including performed plasmas, constrained plasmas and long pulse plasmas. In most of these situations we find the calculated conversion efficiency to be significantly greater than the calculated conversion efficiency of a 1D disc (the usual vehicle for attempting to model conversion efficiency).

For each situation we provide a three step analysis:

1) Show calculationally that the conversion efficiency of a given situation is greater than a 1D disc's.
2) Show that the power balance has been shifted, resulting in more power being available for radiation.
3) Present a "microscopic" explanation of why the power balance has been shifted.

This apparent hodgepodge of special situations is unified by taking it as evidence that conversion efficiency is not an unchanging monolith. Conversion efficiency is a varying quantity which we should expect to be different in different situations.

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

Effects of Long Wavelength Laser Intensity Asymmetries on ICF Pellet Implosions at Moderate Convergence Ratio

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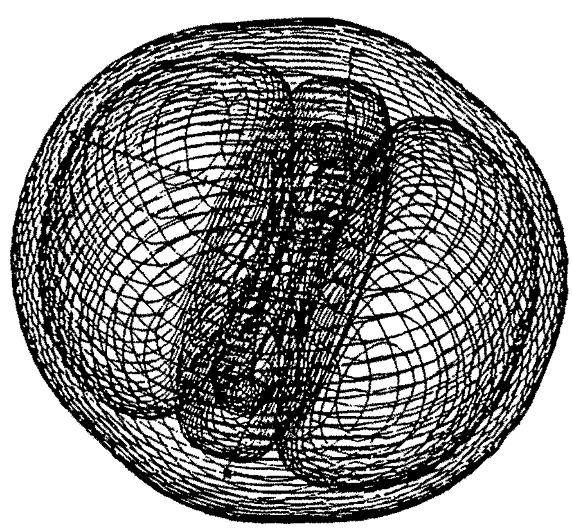
We consider the effects of single Legendre polynomial perturbations on thin imploding spherical shells with convergence ratios on the order of 25. Parameters and initial conditions are chosen to model laser asymmetries in the direct drive problem. Results of simulations using FASTRΘ indicate that long wavelength laser intensity perturbations of even a few percent introduce a seed for the Rayleigh-Taylor [RT] instability. As the shells decelerate deformations grow to significant size. An example shown below is a CH shell at peak convergence, driven by a laser beam with a 1% P_2 nonuniformity. The outer shell is nearly spherical, while the $\rho = 100$ gm/cc surface to the interior of the pellet has been deformed into twin, nearly separate lobes.

Work supported by USDOE and ONR.



3D Rayleigh-Taylor Calculations

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We performed 3D simulations of the growth of single wavelength Rayleigh-Taylor perturbations on the interface between two fluids in either planar-incompressible and spherical-compressible geometries. The simulations were done using LEEOR3D which is a 3D ALE code with interface tracking.

We will describe the shapes which are created from the initial perturbations in 3D, and compare them with RT growth in 2D. We found that two factors determine the final shapes that are created (bubble-ridge or valley-spike). These factors are the initial conditions and the Atwood number.

At the final stages of the growth, we found the bubble and spike velocities to be approximately the same as in cylindrical geometry. We will also address the question of the growth of single-mode perturbations which have various symmetries.

Richtmyer-Meshkov Experiments on Nova at High Compression*

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We are conducting experiments on the Richtmyer-Meshkov instability using the Nova laser at LLNL to indirectly drive planar targets and to generate large compressions. The targets consist of a high density ablator (1.85 g/cc beryllium) and a low density tamper (~0.12 g/cc foam and ~ 1 g/cc plastic) so that the interface is Rayleigh-Taylor stable. The growth and saturation of imposed single wavelength interfacial perturbations are diagnosed with 1D streaked radiographs. The tamper is doped to adjust its opacity to the diagnostic x-rays whereas the Be ablator is transparent so that the radiographs are insensitive to ablation front instabilities . The modal growth and phase are measured with face-on radiography using the 22x Wolter x-ray microscope and the hydrodynamic compression and velocities are measured with side-on radiography using a streaked slit camera. We have taken ~ 40 shots to vary the hydrodynamic parameters: wavelength, initial amplitude, shock and interface speeds, compression, and density ratio. The data is compared with linear theory and 2D hydrodynamic code calculations.

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

Opacity Effects in Indirect-drive Rayleigh-Taylor Experiments on Nova

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An extensive series of indirect-drive Rayleigh-Taylor (RT) experiments was conducted last year on the Nova laser using single-mode planar foils of fluorosilicone[1] (FS) and CH(Br).[2] The main conclusion from comparisons with LASNEX[3] simulations was that the default XSN average ion model predicts substantially too much opacity in the hot ablated material for FS foils. A similar effect exists for the CH(Br) foils, but to a much smaller degree. A single modification to narrow the lines of XSN could not be found that accommodates both the FS and the CH(Br) data. A second conclusion was that once the perturbation evolves into the highly nonlinear state, the observed growth continues slightly longer than the simulated growth, suggesting perhaps that the spikes are wider than predicted.

To address the opacity issue, we arranged to have opacity lookup tables generated[4] using the super transition array (STA) model[5] and using OPAL[6] for LTE atomic structure. Using the STA opacities with LASNEX, the predicted perturbation growth for the FS foils is less than that observed. The result using the OPAL opacity table is essentially identical. We are currently working on the CH(Br) simulations using STA opacities. To assess the second conclusion above, experiments are being planned to look side-on across the ablation front to actually measure the shape of the spike itself. Work was performed under the auspices of the U.S. DOE by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

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Target Designs for Testing the New Los Alamos Nova Ion-Temperature Diagnostic

David Harris and Robert Chrien
Los Alamos National Laboratory

A new ion-temperature diagnostic is being built by Los Alamos National Laboratory for installation on the Nova Laser at Lawrence Livermore National Laboratory. The diagnostic will measure the neutron arrival-time distribution using an array of 960 scintillator-photomultiplier detectors operating in the single-hit mode. The diagnostic will be located outside the Nova target chamber 28 m from the target. The dynamic range of the new detector will cover d-d neutron yields from 5×10^7 to above 10^9. This range will provide coverage for target experiments between the current-mode d-d time-of-flight detectors (yields greater than 10^9) and the Large Neutron Scintillator Array (yields below 10^7) currently on Nova.

Targets have been designed to test this new diagnostic. Additionally, targets have been designed to field the first experiments using this new capability. The planned series of experiments will have two phases. The objective of Phase I is to compare the new ion-temperature diagnostic measurements with that of the existing current-mode time-of-flight detectors. Targets designed to have relatively high ion temperatures and relatively low ion temperatures, both with yields greater than 10^9, will be imploded on Nova. Higher fuel temperatures are achieved by thinning the capsule wall and lowering the initial gas density. Phase I will conclude with targets designed to achieve similar temperatures, but with lower yields (achieved by diluting the deuterium with hydrogen).

Phase II is currently planned to be a series of target experiments where the ion temperature will be measured and compared to calculations as the convergence ratio of the target is increased. Higher convergence implosions will be achieved by lowering the initial gas density inside the capsule. This series will be an initial attempt to help determine the cause of yield degradations measured in high convergence experiments.

Emission spectroscopy of L-shell Xenon as an electron temperature and density diagnostic

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The use of L-shell Xe emission at 5-7 keV is of interest as a diagnostic of core conditions in high performance ICF implosions. This is due to the large pusher opacity expected in these high convergence targets, which will not allow softer K-shell radiation from standard dopants such as Ar to escape. Emission spectroscopy of Ne-like Xe has been examined as a potential temperature and density diagnostic. Experimental data and detailed modeling show that Ne- and F-like emission is not expected unless T_e reaches a minimum value of 1500 eV. Thus, this ionization balance spectroscopy technique serves as a simple and robust diagnostic of the range of electron temperatures present in ICF implosions. In addition, modeling yields the interesting result that there is also a relatively small phase space of electron density in which Ne- and F-like Xe emission is expected. Finally, simultaneous doping of ICF capsules with both Ar and Xe is planned in order to "calibrate" the Xe spectra as a function of the electron temperature and density inferred by Ar K-shell spectroscopy.

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

THE ROLE OF CONTINUUM LOWERING IN OPACITY CALCULATIONS FOR SIMULATIONS OF DIAGNOSTIC SPECTRA

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The measured spectrum of the continuum emerging from laser-imploded targets can yield useful information on the compression parameters. In particular, modifications in the spectrum of the core emission due to absorption by the shell can be related to the areal density ($\rho\Delta r$) of a compressed polymer shell,[1] given an accurate model of the continuum opacity. An important effect in modeling the shell opacity is continuum lowering, which is the reduction in ionization energies due to high-density effects. Our study focuses on continuum lowering because it is an important source of uncertainty in modeling the shell opacity. Under typical implosion conditions, a polymer shell is very highly ionized, and the population of K-shell ions can dominate the opacity, even if most of the ions are fully stripped. This K-shell population is sensitive to continuum lowering. Results of an opacity model can change as various well-known effects are added to the continuum-lowering model, such as a correction to the ion-sphere limit due to the finite size of bound states, and as choices are made among various published simple models. The implications of these results for applying continuum spectroscopy to shell diagnosis will be considered and illustrated by means of simulations.

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REFRACTIVE IMAGE DISTORTION—AN ALTERNATIVE TO INTERFEROMETRY FOR CHARACTERIZING LONG-SCALE-LENGTH PLASMAS

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Refractive image distortion (RID) is proposed as an alternative technique to interferometry for diagnosing low-density, long-scale-length plasmas. A conventional optical probe beam is used, but it is passed through a grid before traversing the plasma. Images of the grid are obtained with the viewing system focused on two or more different object planes within the plasma. These images appear distorted because of refraction in the plasma. From the relative distortions it is possible to infer the refraction angles of each probe "ray" (one ray corresponding to each point on the grid). In principle, RID provides the same information as interferometry (the wavefront tilt), and should therefore yield the density profile of axisymmetric plasmas through Abel inversion. The spatial resolution of RID, while less than that of interferometry, should nonetheless be very adequate for millimeter-sized plasmas. A major advantage of RID is the lack of problems such as fringe blurring that make interferometry difficult.

We have demonstrated the feasibility of RID by analyzing a series of distorted grid images obtained from an experiment carried out at KMS Fusion, Inc., in 1989, using a 50-µm grid.[1] These images were obtained by recording the wavefront holographically and performing reconstructions for 12 different object planes. We have digitized these images and shown that the refraction angles of each ray (in the two orthogonal directions) can be extracted to an accuracy of better than 0.25°. Contours of refraction angle have been found to compare reasonably well with predictions of the hydrodynamics code *SAGE*. Some differences in the lateral extent of the plasma have been found, suggesting that a comparison of RID and simulations could give insight into physical processes such as thermal transport in the target corona.

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This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Agreement No. DE-FC03-85DP40200 and by the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics, which is sponsored by the New York State Energy Research and Development Authority and the University of Rochester.

*Rush-Henrietta High School, Henrietta, NY 14467. Supported by the Laboratory for Laser Energetics Summer High-School Program, which was partially funded by National Science Foundation Grant No. RCD9055084.

BANQUET

Wednesday July 15, 6:30 P.M.

Business Meeting
W. Seka, Chair

Guest Speaker
R.K. Adair

Crossing the Desert Beyond the Standard Model with the SSC

CROSSING THE DESERT BEYOND THE STANDARD MODEL WITH THE SSC

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With the success of the so-called Standard Model, particle physicists believe that they are now very near a complete understanding of elementary particles at energies less than 10^{12} eV, and (in equivalence), fields or forces at distances greater than 10^{-17} cm, or the constitution of the early universe at times greater than 10^{-10} seconds and temperatures less than 10^{10} °K. But, even as atomic physics gives us only a few clues concerning the physics of the nucleus, we have now only a few clues concerning physics beyond the boundaries of the Standard Model. But we *know* that measurements at SSC energies will break the barrier of understanding that now exists and will lead into another layer—hopefully the penultimate—layer of understanding of the fundamental character of the universe. I will sketch some of the reasoning that has led to that conclusion and discuss some of the measurements that we believe will illuminate the next layer of being.

ORAL SESSION IV

B. Bezzerides, Chair

Thusday July 16

PLASMA INTERACTIONS II

THERMAL STIMULATED BRILLOUIN SCATTERING IN LASER-PRODUCED PLASMAS

R. W. Short and E. M. Epperlein
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A new form of the stimulated Brillouin scattering (SBS) instability in laser-produced plasmas is analyzed in the context of recent advances in thermal transport theory. Inverse-bremsstrahlung heating rather than the usual ponderomotive force provides the driving mechanism for the instability. As a consequence of nonlocal thermal transport in the short-wavelength ion waves associated with SBS, the inverse bremsstrahlung heating results in much larger temperature variations than would be predicted by using the classical Spitzer-Harm conductivity. It is found that in low-temperature, high-density, high-Z plasmas the thermal form of the instability dominates and can lead to significantly higher growth rates for SBS.

This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under agreement No. DE-FC03-85DP40200 and by the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics, which is sponsored by the New York State Energy Research and Development Authority and the University of Rochester.

THE STIMULATED BRILLOUIN SCATTERING THRESHOLD IN A HOMOGENEOUS CH PLASMA

D. D. Meyerhofer, A. C. Gaeris, and R. W. Short
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The threshold for stimulated Brillouin scattering (SBS) in a homogeneous CH plasma has been calculated including the effect of two ion species. It is important to retain two ion species rather than use an average ion mode because the phase velocity of the ion-acoustic wave can be comparable to the proton thermal velocity. This leads to strong Landau damping of the wave on the protons and changes the ion-acoustic dispersion relationship. A two ion species calculation of the growth rate has been performed, and it is found that the instability threshold is increased by approximately a factor of 2 over that calculated using an average ion model. In recent long scale-length laser-plasma interaction experiments, red-shifted, backscattered light, a signature of SBS, was not observed. The increase in instability threshold due to the two species model is not sufficient to explain the absence of the SBS signal.

This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under agreement No. DE-FC03-85DP40200 and by the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics, which is sponsored by the New York State Energy Research and Development Authority and the University of Rochester.

*Can Transient Heat Flow Induce Blue-Shifted SBS?

J. S. De Groot†, W. L. Kruer, and H. A. Baldis
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Livermore, CA 94550

In some experiments, a plasma preformed by exploding a thin foil is then irradiated by an intense "instability-generating" laser pulse. Plasma heating by this latter pulse preferentially occurs at the peak density, which leads to a heat flow down the density gradient. The return current associated with this transient heat flow can drive ion waves unstable. These waves can seed Brillouin scattering in the plasma expanding towards (but not away from) the laser, leading to an initial blue spectral component.(1) Some estimates are given to explore this novel possibility.

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(1) H. A. Baldis et al., this meeting.

† Department of Applied Science, U.C. Davis

* 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.

THE EFFECT OF WEAK ELECTRON-ION COLLISIONS ON ION-SOUND WAVE DAMPING

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In the absence of collisions, ion-sound oscillations damp away slowly due to electron Landau damping in a plasma with $T_e >> T_i$. The added effect of weak electron collisions was first considered by Kulsrud and Shen [Phys. Fluids **9**, 177 (1966)] who calculate the electron response by solving the linearized Fokker-Planck equation. They obtain their result by expanding the differential equation in velocity space about the collisionless solution. This yields the curious result that weak collisions actually decrease the damping below the Landau rate. Huang, Chen, and Hasegawa [Phys. Fluids **17**, 1744 (1974)] questioned the validity of this expansion, since it clearly fails for low velocities and for velocities nearly resonant with the wave. Instead, they divide the velocity range into two regions, one with $v > v_b$ and in which collisionless terms are primary, and one with $v < v_b$ and in which collisional effects are dominant. They then solve for $f_e(v)$ in each region and combine the results to obtain the dispersion relation for the wave. Their result is similar to Kulsrud and Shen in that the weak electron collisions decrease the damping, although this term has a very different dependence on the parameters of the problem. However, a numerical solution of the electron Fokker-Planck equation for arbitrary electron collisionality [E. M. Epperlein, to be submitted to Phys. Fluids] has shown no damping reduction in the presence of weak electron collisions.

We show that the Huang *et al.* solution in the lower velocity region is incomplete. The correct solution for $f_e(v)$ for $v < v_b$ yields a nonvanishing contribution to the perturbed density and results in a net electron collisional contribution, which adds to the Landau damping. Thus the effective ion-sound wave damping decreases smoothly and monotonically to the Landau rate as the collisionality vanishes. This behavior has been verified by numerical and analytic solution of the Fokker-Planck equation when restricted to electron-ion collisions only [E. M. Epperlein, R. W. Short, and A. Simon, to be submitted to Phys. Rev. Lett.]. Hence, the expansion method used in Kulsrud and Shen (and in many papers subsequent to it) yields an erroneous solution. A more comprehensive analysis of the electron damping of the ion-sound wave, for all values of the collisionality, is given in an accompanying abstract at this meeting [see Epperlein, Short, and Simon].

This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under agreement No. DE-FC03-85DP40200 and by the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics, which is sponsored by the New York State Energy Research and Development Authority and the University of Rochester.

DAMPING OF ION-ACOUSTIC WAVES IN THE PRESENCE OF ELECTRON-ION COLLISIONS

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The properties of ion-acoustic waves in a plasma are investigated by analytically solving the electron Fokker-Planck and cold-ion fluid equations for arbitrary electron-ion (*e*-*i*) collision strength. It is demonstrated that the effective wave damping can be treated as a combination of collisional and collisionless mechanisms. Contrary to several previous reports, weak *e*-*i* collisions are shown to enhance the damping rate above the electron Landau limit. The predicted enhancement in the damping rate should raise the instability threshold of ion-acoustic type instabilities.

This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under agreement No. DE-FC03-85DP40200 and by the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics, which is sponsored by the New York State Energy Research and Development Authority and the University of Rochester.

THE NONLINEAR DETUNING OF MULTIWAVE INTERACTIONS

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In optical mixing experiments involving high-intensity laser beams, the transfer of energy from the pump to the product wave(s) can be limited by nonlinear phase shifts that detune the interaction. One of the first plasma-based applications in which such an effect was found to be important is the beat-wave accelerator.[1] In this application, the maximal amplitude of the Langmuir wave is limited by nonlinear detuning; pump depletion is relatively unimportant. However, there are many applications in which these two effects are of comparable importance. Analytic solutions of the generalized three- and four-wave mixing equations have been found for the common case in which one of the waves grows from noise.[2,3] These solutions show that the energy-transfer efficiency can always be made to equal the Manley-Rowe limit by choosing the initial phase mismatch of the interaction judiciously. Simple analytic formulae are given for this optimal value of the initial phase mismatch and the resulting energy-transfer length. As an unexpected bonus, the complicated dependence of these important quantities on experimental parameters can be explained completely by simple physical arguments.

1. C. Joshi, W. B. Mori, T. Katsouleas, J. M. Dawson, J. M. Kindel, and D. W. Forslund, Nature **311**, 525 (1984).
2. C. J. McKinstrie, G. G. Luther, and S. H. Batha, J. Opt. Soc. Am. B **7**, 340 (1990) and references therein.
3. C. J. McKinstrie and X. D. Cao, submitted to J. Opt. Soc. Am. B.

This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under agreement No. DE-FC03-85DP40200 and by the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics, which is sponsored by the New York State Energy Research and Development Authority and the University of Rochester.

*The Theory of the Mixed-Polarization High Frequency Instability Inhomogeneous Plasmas

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We consider the parametric instability in which the electromagnetic pump wave decays into two high frequency daughter waves, one of which, the large-k one, is longitudinally polarized. When the wavevector of the second daughter wave becomes vanishingly small, the distinction between longitudinal and transverse polarization loses its significance. If, instead of forcing the polarization of this small-k wave to be strictly longitudinal (which is pure $2\omega_{pe}$), or strictly transverse (which is pure SRS), the instability is allowed to choose its optimum polarization for maximum growth, it is found that in inhomogeneous plasmas mixed polarization states dominate over pure $2\omega_{pe}$ modes for k-values such that $(k/k_0)^2 \leq v_0/c$. Here, v_0 is the oscillatory speed of an electron in the electric field of the pump wave, c is the speed of light, and k_0 is the wavevector of the pump.

Indeed, conventional $2\omega_{pe}$ theory [1] predicts that modes at these k-values are highly stable, while in fact mixed polarization states are found to be unstable. Much more importantly however, in the case of short-wavelength laser-plasma interactions, where $(v_e/c)^2 > v_0/c$ the mixed polarization states are more unstable than the *most unstable modes* of conventional $2\omega_{pe}$ theory. Therefore, in this regime, pure $2\omega_{pe}$ is superseded by the new mixed polarization instability. The threshold for the excitation of these modes is comparable to that of SRS backscatter at $n_c/4$.

The calculation uses a variational approach suited to treat eigenvalue problems which do not necessarily stem from second order ODEs. For the latter, conventional techniques[2] such as local expansions and WKB work exceedingly well, but are not easily generalizable. In the variational calculation, the inhomogeneity is allowed to be any local power law around the perfect phase matching point, thus including both linear and parabolic profiles which are of particular experimental interest. Conventional $2\omega_{pe}$ theory has been restricted to the linear profile case. Using the variational method, the theories of pure $2\omega_{pe}$ and pure SRS have been generalized to an " x^n " profile $\forall n \geq 1$ as well and will be presented in a companion paper.[3]

[1] A. Simon, *et. al., Phys. Fluids* **26**, 3107 (1983).

[2] C. S. Liu, in *Advances in Plasma Physics* Vol. 6, (A. Simon and W. Thompson, eds.) p. 121-177, 1976.

[3] B. B. Afeyan, and E. A. Williams, "A Variational Approach to Parametric Instabilities in Inhomogeneous Plasmas", this volume.

*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.

Breaking of Resonantly Excited Electron Plasma Waves - Solved

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Wavebreaking has a clear meaning in a hydrodynamic model (criteria by Dawson and Coffey). However, strong particle trapping and nonlinear Landau damping may invalidate a fluid description. Nevertheless the scientific community got used to the concept of wavebreaking, although its meaning in the kinetic theory and its relation to the fluid picture remained completely obscure till now. So far there are a few authors only who have been fully aware of this situation For the rest, tentative and vague characterizations of kinetic weavebreaking were given occasionally. Thus two questions arise: (i) what is a meaningful definition of wavebreaking in the kinetic theory, and (ii) what is the appropriate breaking criterion, if kinetic effects are taken into account?

Simulations of high-amplitude electron plasma waves have been performed by solving the Vlasov equation numerically to clarify the mechanism of wavebreaking in smooth density profiles. We show that wavebreaking exists as a phenomenon which is distinct from incoherent hot electron generation and which has a clear meaning in a kinetic theory: By trapping of *entire bunches* of electrons in the wave potential the latter is heavily disturbed and becomes irregular. In contrast to hot electron generation these electron bunches are not accelerated to high velocities. An analytic criterion for wavebreaking is derived which is consistent with the numerical simulations.

INSTABILITY THRESHOLD ANALYSIS FOR LASER-IRRADIATED FLAT TARGETS*

J.M. Wallace, M. Cray

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We shall describe a new model for estimating the likelyhood of parametric instability growth in laser-irradiated targets. The model simply compares the laser intensity throughout the target at a given time with estimates for the intensity thresholds for various absolute and convective instabilities, which are calculated from background plasma conditions. The instabilities considered are SRS/SCS, SBS, $2\omega_{pe}$, and PDI. The model is being implemented as a post-processor for the LASNEX laser-plasma simulation code. Application of the model to recent experiments on flat targets will be discussed.

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

PLasma wave generation in Beat-Wave Experiments with Nd lasers

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P. Benkheiri, F. Jacquet, C. Gregory, Ph. Miné, B. Montes, P. Poilleux and J. Meyer
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C. Stenz
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We present results obtained in a beat-wave experiment performed with both Nd-YAG (λ = 1.064 μm) and Nd-YLF (λ = 1.053 μm) lasers in a D_2 plasma. The two infrared beams together with a green probe beam are focused colinearly in a gas chamber filled with D_2 at different pressures. The green light scattered by the plasma waves is observed in different directions.

In the resonant conditions we observe both intense electron and ion waves. The waves we observe are generated by the decay of beat-wave generated electron plasma waves into electron and ion waves by modulational instability. The electric field is estimated to be of the order of 1 GV/m.

REVIEW TALK IV

R.L. Kauffman, Chair

Thursday July 16

Cryogenic Layers, 10 nm Surfaces, and Other Perplexities of ICF Targets

T.P. Bernat

Cryogenic Layers, 10 nm Surfaces, and Other Perplexities of ICF Targets

Thomas P. Bernat

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Abstract

We are developing methods for forming cryogenic fuel layers for pre-ignition ICF capsules. It has been suggested[1] that cryogenic layers are also necessary for future high-gain direct-drive capsules. We are exploring solid layers formed by the β-layering process, and liquid layers formed with thermal gradients. While both of these techniques work at some level, they each have limits. In the solid case, these limits are associated with the morphology and uniformity of the layer at all scales, while liquid layers are limited in diameter and thickness by the onset of instabilities or material properties. For both the liquid and solid, we are attempting to illucidate these limits through fundamental theoretical and experimental approaches.

Additionally, current and future ICF experiments require improvements in capsule surface finishes down to the 10 nm level, and characterization of the power spectra of the residual imperfections. Testing of hydro instability theories may also be considerably enhanced by tayloring surface perturbations, and we are exploring techniques for doing that.

1. J.T. Larsen, J. Vac. Sci. Technol. A 7(3), May/June 1989, p1150.

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

MIXED POSTER SESSION IV

Thursday July 16

ION KINETIC SIMULATIONS OF SHOCK WAVE FORMATION AND PROPAGATION

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M. Casanova and O. Larroche, CEA-CELV (Limeil)
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The formation and propagation of a planar shock wave has been simulated with our ion kinetic code (1). The shock is formed by the action a a pusher in an initially uniform plasma. By adding a reflecting boundary, we have also studied shock compression of the plasma in 1-D planar geometry. Stability analysis with the Penrose criterion has shown that, although double-humped velocity distributions are seen, the plasma is stable with respect to electrostatic modes of the two-stream and ion-acoustic types. By comparison with fluid simulations of the same situations, assuming classical (Braginskii) ion viscosity and heat conductivity, the kinetic shock structure is far less sharp. We will discuss "ad hoc" modifications to the fluid transport coefficients, so as to reproduce the shock profiles obtained from the kinetic simulations.

(1) M. Casanova, O. Larroche and J.P. Matte,
Phys. Rev. Lett. 67,2143 (1991).

Three Dimensional Simulations of the Rayleigh-Taylor Instability in the Deceleration Phase.

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ABSTRACT

In the Inertial Confinement Fusion approach to fusion a shell containing DT fuel is symmetrically imploded. It is crucial that the shell remains symmetric during the implosion. The symmetry can be disrupted by the growth of the Rayleigh-Taylor (RT) instability during the early acceleration and later deceleration phase and by secular growth during the intermediate coasting phase.

We have developed a 3D hydrocode called PLATO to examine the growth of the RT instability in the deceleration phase of the implosion. Results will be presented of the linear and non-linear regime for a range of mode numbers.

Mixing induced by hydrodynamic instabilities in a laser-driven planar experiment

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Abstract

We have performed experiments at CEL-V on Octal laser system to investigate the mixing development in laser driven planar layered foils.
We have accelerated Si/Al/Au targets with a main laser beam (smoothed by random phase plates) irradiating the silicon. The instability occurs at the aluminum/gold interface where the pressure and density gradients are opposed. The rear surface composition (gold side) have been diagnosed by a probe laser beam in order to excite x-ray lines of the mix region materials.
Mix has been evidenced with high initial Atwood number (≈ 0.8). The mixing development has been investigated using the 1D computer code FCI1 coupled with a k-ε model. The main characteristic is a rapid increase of mix amount which is observed for strong as well as or weak target acceleration.
Null-mix experiments have been performed in the case of Si/Al/Si targets with a small initial Atwood number (≈ 0.1), which allows us to be confident in the probe beam technique [1].
In our last experiments, we have varied gold thickness and temporal delay between main beam and probe beam. Versus the foil thickness, Richtmyer-Meshkov or Rayleigh-Taylor instability is the dominant mechanism. Numerical interpretation and characterization of the mixing zone are on process.

[1] Nuclear Fusion **32**, 670 (1992)

A self - similar model for laser driven ablation

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The results of a detailed numerical study of laser driven ablation do not agree with the results of the well-known steady-state model of Max, McKee and Mead (Phys. Fluids 23, 1620 (1980)) for both planar and spherical symmetries. This discrepancy is the result of the failure of the basic model assumption, i.e. the steady-state assumption.
Recently De Groot et al. (Phys. Fluids B 4, 701(1992)) presented a self-similar model for planar ablation. We present a more general non steady-state model, based upon self-similar solutions of the hydrodynamic equations. It allows a complete description of the flow, including the pre-ablation shock and the under-critical rarefaction wave, and the incorporation of flux-limited conduction. The relevant scaling laws are also derived. This model shows excellent agreement with numerical simulation results.

Numerical Analysis of Nonlinear Mode-Mode Interactions in the Rayleigh-Taylor Instability

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Z. Zinamon
Nuclear Physics Dept., Weizmann Institute of Science.
S.A. Orszag
Applied and Computational Math, Princeton University.

Rayleigh-Taylor (RT) instability results when a low density fluid accelerates a heavier fluid or supports it against gravity. Recent interest in the nonlinear evolution of this instability has been stimulated by work in areas as diverse as inertial confinement fusion and stellar evolution.

We study the interaction of a small number of modes in a two fluid RT instability at relatively late stages of development i.e. the highly non-linear regime, using a two dimensional hydrodynamic code incorporating a front tracking scheme. We find that the interaction of modes can greatly affect the amount of mixing and may even reduce the width of the mixing region. This interaction is both relatively long range in wave number space and also acts in both directions i.e.: short wavelengths affect long wavelengths and visa-versa. We have identified three distinct stages of interaction, including substantial interaction among modes some of which may still be in their classical (single mode) "linear" regime.

A three dimensional hydro-code with interface tracking has recently been developed, enabling us to conduct RT simulations in three dimensions. We have begun comparing the mode interaction and suppression phenomena in 3D with our 2D results. Preliminary results indicate that while there are quantitative differences between the two cases, it seems that in most cases the qualitative behaviour in 3D is similar to 2D.

Reference:

D. Ofer, D. Shvarts, Z. Zinamon, S.A. Orszag, accepted for publication in Phys. Fluids B.

A Numerical Evaluation of Preformed Plasma Effects On Spherical Pinch Inertial Confinement

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The Spherical Pinch is a modified Inertial Confinement Fusion (ICF) scheme designed to improve on the classical ICF model by compressing a preformed hot plasma in the centre of a sphere. This independently generated plasma is confined by means of imploding shock waves launched from the periphery of the vessel through high voltage electrical disharges [1,2].

A one-dimensional, Lagrangian hydrodynamic and heat transfer code, originally developed to simulate ICF pellet implosion, is modified for the Spherical Pinch configuration. The present work examines effects of the preformed plasma on the final density, temperature and confinement time of such a plasma.

Preliminary results show that the presence of the preformed plasma improves on its temperature and confinement parameters. Proper timing of the central and peripheral discharges is required to optimize the fusion characteristics of the central plasma. Results from this study will be presented and the concept's merits will be discussed.

[1] E. Panarella, and P. Savic, J. Fusion Energy 3, 199 (1983)
[2] E. Panarella, J. Fusion Energy 6, 285 (1987)

* Also with the Department of Electrical and Computer Engineering, University of Tennessee, Knoxville, TN 37996-2100

The Spherical Pinch as an X-Ray Emitter: A Numerical Study

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A one-dimensional, Lagrangian hydrodynamic and heat transfer code is being developed to simulate spherically pinched plasmas. This pinch scheme has a central preformed plasma compressed using shock waves launched from the periphery of a spherical vessel. Calculations are made for the Bremsstrahlung emission characteristics in the X-rays region of the spectrum. In particular, this study focusses on soft X-rays in the 1 to 2 keV range, which is of interest for microlithography applications.

The core compression is a sensitive function of the timing between the formation of the central plasma and the launching of the shock waves. An analysis is being carried out to observe the influence of such a timing on the X-rays emission.

Preliminary results will be presented and additional ways of optimizing the emission will be discussed.

[1] P. Savic and E. Panarella, J. Appl. Phys. 59, 3990 (1986)

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MICROINSTABILITY INHIBITED HEAT FLOW AND MICROINSTABILITY ENHANCED NON-MAXWELLIAN DISTRIBUTIONS IN LASER-PRODUCED PLASMA ICF AND X-RAY LASER EXPERIMENTS

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ABSTRACT

The theory of ion-acoustic microturbulence is applied to plasmas with any degree of collisionality. The theory predicts that the heat flux in the presence of ion-acoustic microturbulence can be 10 to 100 times smaller than that due to electron-ion collisions at plasma conditions found in the blowoff regions of laser-produced plasmas. This reduction is consistent with values for the heat flux limiter ($f \cong 0.03$) that are used in descriptions of the hydrodynamics of laser-produced plasmas. The ion-acoustic microturbulence is assumed to be generated by stimulated Brillouin scattering[1] (although if fast electrons are generated another mechanism for its generation has been postulated[2]). Langdon's[3] criterion that inverse bremsstrahlung heating dominates over electron-electron collisions is also reexamined under the assumption that ion-acoustic microturbulence is present in the laser absorption region. When the criterion is satisfied, the Fokker-Planck equation is dominated by the laser heating term and non-Maxwellian electron distributions are generated. It is found that microturbulence lowers the threshold for producing non-Maxwellian distributions by the same factor as the heat flux is inhibited. This finding may have important implications for interpreting x-ray laser or ICF experiments.
Work supported by SDIO/T/IS

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1. W. L. Kruer, "The Physics of Laser Plasma Interactions", Addison-Wesley Publishing Company Redwood City, CA (1988).
2. W. M. Manheimer, Phys. of Fluids **20**, 265 (1977).
3. A. B. Langdon, Phys. Rev. Lett **44**, 575 (1980).

Ponderomotive Force of a Uniform Electromagnetic Wave in a Time Varying Dielectric Medium

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A ponderomotive force associated with a uniform electromagnetic wave propagating in a medium with time-varying dielectric properties is identified. In particular, when a laser ionizes a gas through which it propagates, a force is exerted on the medium at the ionization front that is proportional to $(\nabla\varepsilon)E^2$ rather than the usual $(\varepsilon-1)\nabla E^2$. This force excites a wake in the plasma medium behind the ionization front. The ponderomotive force and wake amplitude are derived and tested with 1-D PIC simulations.

This work is supported by DOE contract no. DE-AS03-83-ER40120 and LLNL.

Electron Plasma Wavebreaking and Caviton Formation†

Bruno S. Bauer

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A very-intense electron plasma wave (electric field energy densities $W = \tilde{E}^2/4\pi n_c T_e > 10^3$) is resonantly excited at the top of a broad, flat density profile by a longitudinal electric field oscillating at the plasma frequency. The waves produce copious energetic electrons and ions (kinetic energy $K > 10^3 T_e$), and create a deep density cavity ($\delta n/n \approx 0.5$) in the resonant region. Reconstruction of the wave, from detailed measurements of electric field amplitude and phase, demonstrates wavebreaking and accounts for the observed energetic particles. Calculation of the ponderomotive force of the localized plasma wave yields an ion flow comparable to that observed in the experiment. Processes are studied with a variety of indirect and *in situ* diagnostics. Results are compared with those of a one-dimensional particle-in-cell computer simulation. This study helps illuminate strong Langmuir turbulence phenomena and is relevant to laser-plasma and ionospheric-heating experiments.

†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.

*A Variational Approach to Parametric Instabilities in Inhomogeneous Plasmas

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A variational method is devised to calculate the properties of the most unstable mode of a given parametric instability. The construction of the variational principle, its simplification and approximation and its relationship to similar work in laser theory,[1] drift waves in sheared magnetic fields,[2] leaky waveguides, [3] and other non-self adjoint eigenvalue problems [4] will be discussed.

The method is used to calculate the growthrate, frequency and threshold condition for two model problems and then applied to two specific instabilities. These are the Rosenbluth model equations[5] and the Liu, Rosenbluth and White sidescattering model equation.[6] In both, a power law inhomogeneity profile is used and previously known results are recovered and extended.

The specific instabilities considered subsequently are SRS and $2\omega_{pe}$. In the case of SRS, the temporally growing instability in a parabolic profile is treated, where the scattering direction is allowed to vary so as to include all angles from backscattering to sidescattering, with the apex of the density profile assumed to be at or anywhere below the quarter-critical surface. In the case of $2\omega_{pe}$, a parabolic profile is treated for the first time and the perfect phase matching point (PPMP) is allowed to be at the apex or anywhere below it. Near the apex, a new regime of instability is identified, with a lower threshold than that of a linear profile[7], as one would expect. As the PPMP moves away from the apex, the growthrate is found to smoothly reduce to the linear profile result.

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[7]A. Simon, *et. al., Phys. Fluids* **26**, 3107 (1983).

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Studies of Stimulated Brillouin Scattering Using a Hybrid Particle Ion/Fluid Electron Code*

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We have developed a hybrid simulation code to study SBS in long scale length, underdense plasmas. This is a hybrid code that has mobile ions, fluid electrons, and differences the electromagnetic fields using the Langdon-Dawson advective scheme. It is quite fast, and allows one to study kinetic effects on the ions for realistic times (100 psec) and lengths (500 μm), even when a realistic mass ratio is used. This simulation code easily runs on an HP workstation. It has been quite useful in providing insight into such issues as ion profile modifications with realistic mass ratio, harmonic generation, expanding plasmas, and ion heating as a saturation mechanism. We compare the results of the code to some recent experiments. In addition, we are also using it to study the effects of bandwidth and random phase plates on the SBS instability, as well as studying SBS when future hohlraum parameters for the NOVA upgrade are used. We are in the process of putting in a Debye length correction to expand the parameter regime the code is capable of looking at.

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TRANSVERSAL CHIRP IN SRS PULSES

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The copropagation of short pump, signal and Stokes quasi-solitons in uniform unbounded plasmas is studied taking into account the diffraction effects. The initial phase of the spacio-temporal 3D evolution of interacting pulses is described for small reciprocal Fresnel numbers using perturbation method developed earlier [1].

It is shown that the pump pulse, having initially a given transversal energy distribution (Gaussian or super-Gaussian) as well as the other interacting pulses, become strongly modified due to the competition between the Fresnel diffraction, nonlinear effects and crosstalk between pulses.

The steepness of the initial radial shape of the pump as well as the magnitude of the Fresnel number are the most important parameters in the reshaping process. The most critical region is the cylindrical shell having the radius equal to the waist thickness of the Gaussian (of any order) profile of the pump. In the vicinity of this shell strong phase variations take place. As a consequence, radial energy currents (outwards via the diffraction effects, inwards via the nonlinearity) develop leading to radial redistribution of energy inside the pulses and formation of Fresnel rings. The phase variations generate radially dependent chirp in all pulses.

The theory can be generalized to the case of non-uniform plasmas as well as to more general 3 wave interactions.

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SATURATION OF STIMULATED RAMAN SCATTERING BY LANGMUIR AND SOUND WAVE COUPLING

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Numerical and theoretical studies of stimulated Raman scattering (SRS) based on the one dimensional Zakharov-Maxwell equations are presented for a wide range of plasma parameters relevant to present day experiments. Our results are obtained for a homogeneous, finite plasmas with no coupling to stimulated Brillouin scattering. The primary nonlinear process affecting evolution of SRS is a parametric decay instability (PDI) of the resonant Langmuir wave.

After initial linear growth SRS saturates producing at first a sharp peak in reflectivity of the approximate duration defined by the PDI growth rate $\sim 1/\gamma_{PDI}$. The following intermediate nonlinear regime is dominated by the PDI cascade, which is usually disrupted after the second stage. The truncation of the PDI cascade is caused by the Langmuir field localization due to the spatial evolution of PDI. Duration of the transient nonlinear regime depends on ion acoustic damping $\sim 1/\gamma_A$. For $\gamma_{PDI} \gg \gamma_A$ SRS is dominated by bursts of reflectivity in the intermediate regime. Asymptotic saturation follows the intermediate stage and is characterized by relatively low average values of reflectivity. The scaling law for final saturation levels varies linearly with laser intensity and it is proportional to L^3 for the low reflectivity results. This compares reasonably well with our numerical results. Our scaling of the Langmuir wave amplitudes depend on the PDI threshold (cf. the hypothesis proposed by R. P. Drake and S. Batha, Phys. Fluids B3, 2936 (1991)) but it is also a function of length and laser intensity.

A comparison between wave coupling models describing SRS and PDI, and the Zakharov model will be also presented. Very important differences between these two approaches are related to the initial fluctuation levels for the secondary instabilities like PDI. The nonresonant wave coupling mechanisms tend to enhance them well above thermal levels in case of the Zakharov theory.

(a) On leave from P. N. Lebedev Physics Institute, Moscow, Russia.

SPATIOTEMPORAL CHAOS IN THE THREE-WAVE INTERACTION

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The three-wave interaction plays a prominent role in laser-plasma interactions. We have studied in detail the space-time evolution of the non-conservative, nonlinear three-wave interaction where a growing pump wave decays into two damped daughter waves. The case when the pump wave has the largest group velocity is of particular importance as this situation corresponds to the Langmuir decay instability of a growing electron plasma wave. Numerical simulations show that in this case the pump and daughter waves saturate at a finite amplitude and their space-time profiles are drifting coherent spatial structures that evolve chaotically in time. Thus, for the Langmuir decay process, the system exhibits spatiotemporal chaos [1]. The correlation function for the three waves has definite length and time scales and the three waves acquire bandwidths in frequency and wavenumbers. The simulation results can be understood in terms of the solutions obtained by inverse scattering transform of the conservative three-wave interaction. Perturbation around these solutions give the length and time scales observed for the pump and daughter waves.

This work is supported by Lawrence Livermore National Laboratory Subcontract No. B-160456 and National Science Foundation Grant No. ECS-88-22475.

[1] C. Chow, A. Bers, and A. K. Ram, to appear in *Physical Review Letters* (June, 1992).

NONLINEAR OSCILLATION AND CHAOS IN BACKWARD FOUR-WAVE MIXING

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The four-wave mixing of optical radiation in plasmas is a process of considerable current interest.[1,2] We have studied the nonlinear interaction of two counterpropagating pump waves, both of frequency ω_0, and probe and signal waves of frequency $\omega_0 - \omega$ and $\omega_0 + \omega$, respectively. The four-wave model used in this study is a simplified version of that for the transverse modulational instability of counterpropagating light waves[3] and is closely related to idealized models of three-wave backscattering instabilities.[4] Analytical and numerical results for the spatio-temporal evolution of each wave, including nonlinear saturation, nonlinear oscillation and chaotic evolution, are given for several different parameter regimes. A key issue to be resolved is how the system determines its dynamical behavior when there exist several possible steady states, as is the case for pump intensities that are well above their threshold values for absolute instability.

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2. A. Lal and C. Joshi, J. Opt. Soc. Am. B **8**, 2148 (1991).
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4. C. J. McKinstrie and A. Simon, Phys. Fluids **29**, 1959 (1986) and references therein.

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NONLINEAR SCHRODINGER SELF-FOCUSING IN PLASMAS
The Core and the Halo

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ABSTRACT

Nonlinear focusing is studied using the NonLinear Schrödinger (NLS) equation (with imposed axial symmetry) for realistic saturating nonlinearities: electron-only focusing (ENLS), ambipolar fluid ponderomotive effects (PNLS) and a simple saturating model, i.e. $|E^2|E/(1+|E^2|)$. At powers much greater than threshold there is a characteristic sequence of focusing events, with some satellite light escaping each focusing event. The implications of this phenomenon and the relevant diagnostic possibilities will be discussed.

Observations of MeV electrons and Scattered Light in Intense, Subpicosecond Laser-Plasma Interactions

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and

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Abstract

We are presently investigating the interaction of a 1.05 μm, 0.8 psec., 10^{18} W/cm^2 ($v_{osc}/c = 0.8$) laser pulses with plasmas preformed on solids. Using a magnetic spectrometer, direct observations of megavolt electrons have been made along the propagation direction of the incident laser. Spectrally resolved backscattered and specularly reflected ($\theta_{inc} = 22.5°$) laser light reveal the presence of the 3/2ω, 2ω, 3ω, and 4ω harmonics. A preliminary summary and current status of the work will be given.

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.

X-RAY LINE POLARIZATION SPECTROSCOPY OF LASER PRODUCED PLASMAS

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Non local heat flow has received a considerable theoretical attention because it has a significant impact on inertial confinement fusion, X-ray laser and ultra-short plasmas. To address this issue experimentally, we use X-ray line polarization spectroscopy[1]. We present a study of the second order anisotropy (f_2/f_0) of the electron distribution (which is a manifestation of non local transport) using the polarization[2] of Al He_α lines.

Experiments were realized with short high intensity 1 μm pulses incident on low temperature preformed plasmas. We use a 1 ps pulse at 8 x 10^{14} W/cm^2 with a 30 ps prepulse at 8 x 10^{11} W/cm^2 and more recently a 400 fs pulse at 10^{16} W/cm^2 with a 300 ps prepulse at 3 x 10^{10} W/cm^2 to probe f_2/f_0. The polarization diagnostic will be described and the experimental data will be compared to electron kinetic simulations. The perspectives of this diagnostic for two beam experiments with controlled preplasma gradient scalelength will be discussed.

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Self-Guiding of a Subpicosecond Laser Pulse in a Neutral and Ionized Gas

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By focusing high peak power, 1 μm, subpicosecond laser pulses, we observed multiple foci formation of the laser beam in a vacuum chamber backfilled with air or hydrogen. We interpret it as the result of simultaneous action of self-focusing by the nonlinear refractive index of the bound electrons, and defocusing by the plasma the laser pulse creates, plus the natural diffraction of the laser beam. Quasi-stationary computer simulations show the same multiple foci behavior as the experiments. The results suggest much larger nonlinear electronic susceptibilities of a gas near or undergoing ionization in the high field of the laser pulse. Optical self-guiding will allow the creation of long, highly ionized plasma columns required for various applications including x-ray lasers and novel laser plasma electron accelerators.

4P21

K-shell emission from 140 femtosecond laser-produced plasmas created from porous aluminum targets

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ABSTRACT

The K-shell emission from flat and porous aluminum targets is used to infer the efficiency of creating a high temperature (>100eV), thermal plasma with 800 nm, 140 fs laser light. The K-shell emission from flat aluminum targets is found to be significantly less than that of the porous targets, implying a lower temperature and less efficient coupling between the target and ultra-short pulse laser light.

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Picosecond-Plasma Temperature Measurements by Ratio of Isoelectronic Lines

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Ideal picosecond plasmas could be expected to be highly collisional, and in local thermodynamic equilibrium. Realistically, laser prepulse (preionizing the target and producing a less-collisional plasma target for the intense subpicosecond pulse) and the prospect of nonlocal transport and nonthermal electron distributions make the atomic physics of such plasmas more difficult, and spectroscopic diagnosis more interesting.

We have developed a novel temperature diagnostic which is broadly applicable, suitable for highly transient plasmas and which can be simply characterized where the electron distribution may not be thermal. It uses targets which consist of a known ratio of two elements of similar atomic number, comparing isoelectronic lines from ions which differ only in their nuclear charge Z, and thus in their ionization potentials χ_i. Since these two have different values of the same dimensionless parameter T_e/χ_i, the ratio of intensities of isoelectronic lines can be interpreted to determine the temperature T_e.

We describe our investigations of this technique, applying it to plasmas created from solid targets of NaF, KCl and Mg/Al alloy. We present theory and experimental results comparing temperatures produced by λ=1 μm laser pulses ranging from 1 ps, 10^{17} W cm^{-2} to 600 ps, 10^{14} W cm^{-2}. We expect to describe the differences we see between prepulsed irradiation and clean-pulse irradiation, and describe the suitability of the isoelectronic ratio technique over this wide range of conditions.

The Evolution of Electromagnetic Pulses in Two-Dimensions

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and

T. Katsouleas, T.C. Chiou
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The evolution of a short intense laser pulse propagating in a plasma is examined with two dimensional PIC simulations. The pulse is followed over many Raleigh lengths with the use of a moving code. Optical guiding mechanisms such as self focusing and channeling are investigated. Preliminary results are presented.

This work is supported by DOE contract DE-AS03-83-ER40120 and LLNL.

ELECTRON KINETIC SIMULATIONS OF INTENSE, ULTRA-SHORT LASER PULSE INTERACTION WITH SOLID TARGETS.

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Recent experiments by our group were done with very high contrast (10^{-9}), thanks to frequency doubling. Thus, a very clean 400 fs (FWHM), 10^{16} W/cm^2 pulse was normally incident on an aluminium solid target. Kinetic simulations with our electron kinetic code FPI (1), to which we have added an EM wave solver to simulate skin effect absorption in the over-dense plasma, indicate that the laser energy is absorbed at densities far above critical, but somewhat below solid, because the density scale-length is only a few hundred Angstroms. We have included simplified average ion atomic physics in the code, which includes ionization and excitation from either the ground state or excited states, as well as continuum lowering. The simulations indicate that most of the absorbed energy is spent in ionizing the plasma. Strongly non-maxwellian features are seen in the electron velocity distribution functions. This is due in part to non-local transport and strong absorption, somewhat as was observed in long pulse simulations (1), but also to electron acceleration by the extremely strong ambipolar field, due to the ultra-steep density gradient in the absorption region.

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Interaction of the Short Powerful Electromagnetic Pulse with Dense Plasma Layer

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Particle in cell method was used for numerical simulation of the subpicosecond powerful linearly polarized laser pulse absorption in a dense plasma slab with sharp boundaries for the case of normal incidence. Ions were treated as a uniform background. The electron plasma frequency ω_p was assumed to be about 30 times larger then the laser frequency ω_0. The laser radiation penetrates into the plasma no more than skin depth $\sim c/\omega_p$, where c is the velocity of light. The electron distribution function and mean electron energy were obtained in self-consistent manner as a result of balance between laser energy absorption from the front side of plasma slab and electron energy transport through the rear plasma boundary.

Four-dimensional phase space (one coordinate and three velocity components) was used in simulations. Self-consistent Darwin (non-radiative) model was applied to describe particle motion field distribution inside plasma. The temporal step was about the inverse plasma frequency, spatial was of the order of Debye length.

It was found that for laser intensities I_0 of $10^{17} - 10^{19}$ W/cm^2 the absorption coefficient A slightly decreases (as $I_0^{-0.12}$) from 24% to 13%. The electron distribution function was strongly anisotropic (the energy in the plane of polarization was 3–4 times larger then that in the third dimension), mean electron energy oscillates with frequency twice as laser frequency and increases with laser intensity as $I_0^{0.33}$. The electron transport inhibition has not observed in these runs may be due to small plasma thickness and/or lack of spatial dimensions of the code.

The relevance of these simulations to real laser-plasma experiments will be discussed.

ORAL SESSION V

J.P. Dahlburg, Chair

Friday July 17

X-RAY LASERS

&

ULTRASHORT PULSE INTERACTIONS II

Space- and Time-resolved Study of Ne-like Emissions in Ge X-ray lasers

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We have studied germanium laser line plasmas (12 mm long) obtained with irradiations of about 1.5 x 10^{13} W/cm^2 with NRCC's LP2 Nd: glass laser, operating at 1.06 μm. The experiments were conducted in gain conditions, at various energies. Two focussing arrangements were used: a conventional crossed cylindrical lens system and a segmented wedge array system to create more uniform plasmas. The line plasmas exhibit inhomogeneities on the scale of millimeters along the focal length. Time- and space-resolved monochromatic imaging was used to study the temporal evolution and the spatial distribution of the Ne-like emission for various pulse lengths (100 ps and 1.5 ns), various rise times (200 ps and 1 ns) and focussing system. Space- and time-resolved quadrupole (E2) and dipole (3A and 3C) Ne-like emission are discussed and their use as potential plasma diagnostic is outlined.

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Optimized coherence in single-stage x-ray lasers

by

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&

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Current x-ray laser (XRL) designs rely on amplifying spontaneous emission in a high temperature plasma. An important issue in the study of XRL's is the degree of transverse spatial coherence necessary for holographic applications. Longitudinal coherence appears to be satisfactory, but transverse coherence remains problematic and requires further optimization study.

The role of smoothly varying transverse gain and refraction profiles on x-ray laser coherence is analyzed by modally expanding the laser electric field within the paraxial approximation. Comparison with a square transverse profile reveals that smoothly varying profiles generally lead to a greatly reduced number of guided modes and a consequent improvement in transverse coherence length. However, the refractive defocussing responsible for enhanced coherence can also significantly degrade the coherent power of plasma x-ray lasers based on amplified spontaneous emission. A critical value of Fresnel number is indicated, below which the coherent power rapidly decreases as refractive defocussing is increased. A parameter study of transverse coherence for current or planned x-ray laser experiments is provided. Comparison with ray optics scaling laws for transverse coherence length and coherent power is made. An optimal coherent energy output of nearly 500 μJ in 100 psec is determined in Ni-like Ta at 45Å for a saturated single-stage x-ray laser. For holographic imaging of live biological samples at a resolution of 300 Å, this output compares favorably with estimated requirements.[1]

[1]R.A. London, M.D. Rosen, and J.E. Trebes, *Applied Opt.* **28**, 3397 (1989).

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Measurements of Coherence and Beam Patterns in Yttrium X-Ray Lasers*

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We measured gain, beam patterns, and transverse coherence lengths in single-side-irradiated yttrium exploding-foil x-ray lasers at the Nova Two-Beam Laser Facility. Additional shots have successfully coupled the x-ray laser output from one yttrium target to a second yttrium target with a spatial separation of 29 cm. The long distance between the targets provides a spatial filter which can improve the coherence of the yttrium laser. New instrumentation developed for these experiments include a fully time-resolved coherence diagnostic (which records a multiple-slit interference pattern) and wide-angle extreme ultraviolet spectrographs and beam divergence cameras.

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

Time-dependent ray and wave optics modeling of x-ray propagation in exploding foil line-focus laser plasmas*

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We have calculated x-ray amplified spontaneous emission from exploding foil line-focus laser produced plasmas relevant to experiments at the Lawrence Livermore National Laboratory (LLNL). Two dimensional time-dependent hydrodynamics computed by LASNEX and a gain profile based on XRASER calculations are input into two x-ray propagation codes, CASER and WAVE. CASER solves the radiation transport equation along three dimensional ray orbits, while WAVE integrates the paraxial wave equation along characteristics. We have modeled Neon-like Yttrium x-ray laser experiments at LLNL which used $100\mu g/cm^2$ targets irradiated from one side with a 500 ps FWHM Gaussian pulse shape at $0.53\mu m$, with a $120\mu m$ line focus and irradiance 1.3×10^{14} W/cm^2. We have obtained good agreement with experimentally determined far field beam footprints, gain curves, and coherence. The ray and wave optics results are also in good agreement. These results give confidence that our modeling can be used as an effective design tool.

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

†Laboratory for Laser Energetics, University of Rochester, Rochester, NY 14623

Effects of plasma dispersion in ultra-short pulse x-ray lasers

by

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The ongoing development of ultra-short pulse (τ<100 fsec), high intensity (I>10^{18}W/cm^2) optical lasers brings closer the possibility of demonstrating x-ray lasing by recombination following optical-field-induced ionization (OFI). The idea of a table-top x-ray laser based on OFI consists of an initially neutral gas which is stripped nearly instantaneously to a desired ionization state by an intense optical or UV pulse of wavelength λ in a high f-number confocal region. Following passage of the ionizing pulse, the electrons quickly recombine into the upper Rydberg states and then cascade to successively lower atomic levels. A sequence of population inversions ensues which culminates in the occurrence of lasing to the ground state. For example, in Li-like Ne lasing occurs at 98Å between the $3d^{5/2}$ and $2p^{3/2}$ levels. Despite the short duration of population inversion from fast collisional-radiative filling of the ground state, substantial radiation can be generated for two reasons. First, the small-signal gains are often large which leads to large amplification followed by saturation after only several millimeters of propagation. Second, after saturation the x-ray pulse may continue to longitudinally track and (linearly) amplify behind the ionizing laser pulse. However, an important phenomenon not considered previously is the effect of plasma dispersion on the relative speeds of the ionizing laser pulse and x-ray photons. For example, in a plasma with $n_e=5\cdot10^{20}$cm^{-3} and λ=0.25μm, the x-ray photons overtake the UV pulse after only one centimeter of propagation. Thus, plasma dispersion acts to reduce the interaction length of x-rays with the gain medium, thereby affecting the amplification and saturation properties of the laser. The concern is that the high efficiencies associated with higher density and longer laser length previously reported[1] may not be accessible due to possible reduction of amplification from the effects of plasma dispersion.

We show by carefully following the time history of x-ray photons that dispersion acts to bound the x-ray intensity along the laser and to stretch the pulse in time, thus coincidentally giving a saturated output energy fluence that increases with laser length as in the non-dispersive regime. High output efficiencies $\eta>10^{-4}$ in Li-like Ne at 98Å are thus accessible in x-ray lasing plasmas of high density $n_e>5\cdot10^{20}$cm^{-3}, low temperature T_e<40eV and large radius a>20μm, despite significant dispersion.

[1] P. Amendt, D.C. Eder, and S.C. Wilks, *Phys. Rev. Lett.* 66, 2589 (1991).

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.

Intense Laser Pulse Propagation and Wakefield Generation in Plasma*

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The propagation of intense laser pulses in underdense plasmas has widespread importance in a number of areas, including laser wakefield acceleration.[1,2] The recent development of compact terawatt lasers gives additional impetus to these applications. In vacuum, the focused laser propagation distance is limited to a few Rayleigh lengths. In plasmas, nonlinear and relativistic effects associated with intense lasers can significantly modify the propagation characteristics of the laser.[1,2] The large differences between the laser wavelength and other characteristic axial lengths in the system, i.e., propagation distance, pulse length and plasma wavelength, make the direct numerical integration of the dynamical equations over extended distances impractical.

A nonlinear, relativistic, 2D–axisymmetric laser–plasma propagation model has been formulated and numerically evaluated for ultra–intense laser pulses in plasmas. The formulation has a number of unique features which allow for numerical simulations to be carried out over extended laser propagation distances. The appropriate Maxwell–fluid equations are recast into a convenient form by (i) performing a change of variables from the laboratory frame (r, z, t) to the speed of light frame $(r, \zeta = z - ct, \tau = t)$, (ii) applying the quasi–static approximation,[1] and (iii) averaging over the fast spatial scale length, i.e., the laser wavelength. The resulting equations are used to study the (i) failure of relativistic focusing for short laser pulses, (ii) modulation of long laser pulses by wakefield effects, (iii) optical guiding of tailored laser pulses, and (iv) use of plasma density channels to guide intense laser pulses. Wakefields generated by guided laser pulses can trap and accelerate a trailing electron bunch to high energies.

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[2] P. Sprangle and E. Esarey, Phys. Fluids B, July (1992).

SELF FOCUSING AND RAMAN SCATTERING OF ULTRA SHORT LASER PULSES IN TENUOUS PLASMAS

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The propagation and self focusing of short intense laser pulses in a tenuous plasma is studied both analytically and numerically. Specifically, pulses of length of the order of a few plasma wavelengths and of intensity which is large enough for relativistic self focusing to occur are considered. Such pulses are of interest in various laser plasma acceleration schemes. It is found that these pulses are likely to be strongly affected by Raman instabilities. Two different regimes of instability, corresponding to large and small scattering angles, are found to be important. Small angle scattering is perhaps the most severe since it couples strongly with relativistic self focusing leading the pulses to acquire significant axial and transverse structure in a time of the order of the self focusing time. Thus, it will be difficult to propagate smooth self focused pulses through tenuous plasmas for distances longer than the Rayleigh length, except for pulse duration of the order of the plasma period.

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"High-harmonic Generation from Femtosecond Laser-irradiated Solids"

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We investigate the radiation from a solid body which is illuminated by an intense ultrashort laser pulse. Since the expansion of the body due to heating by light absorption is small during femtosecond laser interaction, the laser field (E) penetrates into a medium with periodically distributed ions. Free electrons which are located within this structure will be accelerated by the laser field, but additionally feel the force originating from the periodic potential of the lattice. This causes harmonic radiation in multiples of the laser frequency ω_0, provided that the excursion amplitude of their oscillations in the laser field assumes values much larger than the lattice constant a. A typical spectrum consists of a large number of harmonics with amplitudes of similar magnitude (i.e. non-drecreasing), but still small compared with the incoming laser flux. The spectrum breaks off beyond the harmonic number n that is comparable to the number of lattice periods which a free electron passes during its excursion $\delta = eE/m\omega_0^2$ in to the laser field, i.e. $\omega_n/w_0 = n > 2\pi\delta/a$. We investigate this effect taking into account collective electron motion and using realistic periodic potentials. We also discuss additional aspects connected with a finite field penetration into the irradiated layer. We conjecture that high-harmonic radiation from free electrons should be observable as long as the periodic structure in the skin layer survives. This is certainly the case during a considerable fraction of a femtosecond laser pulse.

THE DENSE PLASMA HEATING BY ULTRASHORT POWERFUL LASER PULSES IN THE REGIME OF AN ANOMALOUS SKIN EFFECT

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The processes of laser light absorption in dense plasmas and plasma heating have been studied in the regime of the anomalous skin-effect which is relevant to future interaction experiments of subpicosecond laser pulses with intensities greater than $10^{17} W/cm^2$ and high contrast ratio with solid targets.

We have analyzed the dependence of the absorption coefficient on the angle of incidence and polarization of the laser pump as well as on the shape of electron distribution function in the skin layer. The anisotropy of electron distribution function may lead to an additional increase in the absorption coefficient and to the changes in its angular dependence.

The energy transport from the surface layer of absorption into inner parts of plasma has been analyzed by numerical solutions of $1\frac{1}{2}D$ Fokker-Planck kinetic equation and by using $1D$ analytical results based on the classical heat transport and on the recently proposed models of the inhibited heat transport. In the kinetic model the laser energy absorption in a skin layer has been treated as the special kind boundary condition for the electron distribution function. In analytical studies the approximate shape of the heat wave has been taken from numerical results.

The numerical solutions have shown that for the high laser intensities the electron distribution function becomes nonstationary, anisotropic and differs considerably from the equilibrium distribution. It exhibits a deficit of slow and fast particles as compared with Maxwellian distribution function. Due to strong energy transport inhibition the electron heating rate is approximately ten times higher as compared with values consistent with classical heat conduction.

The analytical model of the inhibited heat transport has been used in derivation of plasma temperature and heat wave thickness scaling laws with respect to time and laser pulse parameters. We have also outlined the range of parameters where anomalous absorption and anomalous heating of solid targets could be important.

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