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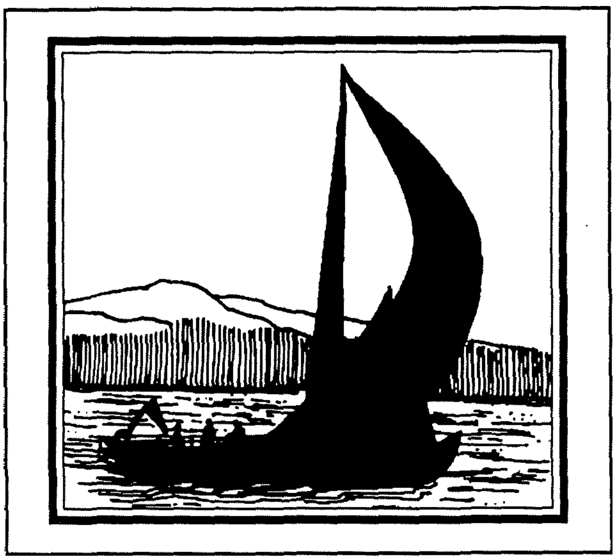
20th Annual Anomalous Absorption Conference

Sugarloaf Resort
Traverse City, Michigan
July 9 - 13, 1990

KMS

20th Anomalous Absorption Conference



9-13 July 1990

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Traverse City, Michigan

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20th Annual Anomalous Absorption Conference
9-13 July 1990
Sugarloaf Resort, Traverse City, Michigan

Monday Morning, 8:30 AM, 9 July
M. Cray, Chair

Oral Session - Energy transport and hydrodynamics (15 minute each)

1O1 Studies of the first-shock effects in ICF capsules
S. V. Coggeshall, N. M. Hoffman, and A. Hauer

1O2 Hydrodynamic modeling of NIKE target experiments
J. H. Gardner, J. P. Dahlburg, M. H. Emery, and S. E. Bodner

1O3 Theoretical analysis of high density compression of plastic shell targets
K. Mima, A. Nishiguchi, H. Azechi, N. Miyanaga, H. Takabe, K. Nishihara, M. Nakatsuka, T. Jitsuno and S. Nakai

1O4 Simulation of the ablatively driven inner surface Rayleigh-Taylor instability
J. P. Dahlburg, J. H. Gardner and M. H. Emery

1O5 Representing the linear growth of fluid instabilities in a turbulence transport model
N. Hoffman

1O6 Collision and interpenetration of plasmas created by laser illuminated thick foils: Experiment
R. L. Bosch, R. L. Berger, G. Charatis, N. D. Delamater, B. H. Failor, W. B. Fechner, and E. F. Gabl

1O7 Collision and interpenetration of plasmas created by laser illuminated thick foils; Interpretation
R. L. Berger, R. A. Bosch, N. D. Delamater, B. H. Failor, W. B. Fechner, and R. Kauffman

1O8 The effect of smoothing by spectral dispersion (SSD) on burnthrough measurements using the Omega laser system
D. K. Bradley, J. A. Delettrez. P. A. Jaanimagi, and C. P. Verdon

1O9 Hydrodynamic target response to an ISI-smoothed laser beam
M. H. Emery, J. H. Gardner, R. H. Lehmberg, and S. P. Obenschain

1O10 Optical probing diagnostics for the Omega upgrade
R. S. Craxton, W. Seka, and D. Brown

Monday Evening, 7:30 PM, 9 July
C. Labaune, Chair

Review Talk (45 minutes)

Heavy ion fusion versus plasma physics
A. Bruce Langdon

Mixed Poster Session

1P1 Rayleigh-Taylor experiments using shaped laser pulses
B. A. Remington, S. Haan, G. Glendinning, J. Kilkenny and R. Wallace

1P2 Instability growth in direct drive inertial confinement fusion
S. V. Weber, S. W. Haan, and M. Tabak

1P3 Calculated radiographic signatures of fluid instability growth in ICF implosion
B. H Failor and A. Hauer

1P4 An alternative inertial confinement scheme, the spherical pinch, a numerical evaluation
D. Mostacci, K. Kawai and E. Panarella

1P5 Aluminum coated optical fibers as infra-red (1w)timing fiducials for synchronizing x-ray streak cameras
J. A. Koch and B. J. MacGowan

1P6 The generation of tunable radiation using an underdense ionization front
W. B. Mori

1P7 Examination of x-ray conversion on Au:Be dilution experiments using the DDP code
M. J. Dunning, C. J. Cerjan, P. A. Vitello, and D. R. Kania

1P8 UV Thomson scattering from x-ray laser plasmas
H. A. Baldis, B. La Fontaine, D. M. Villeneuve, J. Dunn, G. D. Enright, P. E. Young, M. D. Rosen and D. L. Matthews

1P9 Monte Carlo simulation of complex atomic spectra for opacity calculations
M. Klapisch, P. Duffy and W. H. Goldstein

1P10 Soft x-ray generation from picosecond KrF laser pulses
J. N. Broughton and R. Fedosejevs

1P11 Simulations of beam smoothing
B. F. Lasinski, R. L. Berger, W. L. Kruer, A. B. Langdon and E. A. Williams

1P12 A study of the effects of optical smoothing on ponderomotive filamentation using self-consistent wave-kinetics
E. R. Tracy, A. J. Neil and A. H. Boozer

1P13 Three-dimensional filamentation and optically smoothed light
A. J. Schmitt and R. H. Lehmberg

1P14 Simulation of ponderomotive filamentation in laser-produced plasmas
C. E. Southwell, E. F. Gabl, R. L. Berger and J. P. Sheerin

1P15 Relativistic self focusing of short laser beams in plasmas
P. Mora and P. Ciseau

1P16 Collapse dynamics in 2-d Zakharov equations
L. Berge' and G. Bonnaud

1P17 Vlasov simulation of nonlinear resonant absorption and wave breaking
A. Bergmann and P. Mulser

1P18 Frequency upshifting and chirping of sub-picosecond laser pulses via time dependent plasma densit
S. C. Wilks, W. L. Kruer, A. B. Langdon, and J. M. Dawson

1P19 Suppression of the pedestal and pre-pulse in a chirped-pulse-amplication laser
Y-H Chuang and D. D. Meyerhofer

1P20 Production of high contrast sub-picosecond laser pulses from pulse compressed ND lasers
Y. Wang, R. Dragila and B. Luther-Davies

1P21 Energy balance and transport in short gradient scalelength plasma
T. Auguste, M. Chaker, J. C. Kieffer, H. Pepin, J. S. Coe, C. Ching - Juan, and G. Mourou

1P22 Compression of magnetic flux by laser irradiation
W. Choe

Tuesday Morning, 8:30 AM, 10 July
T. Johnston, Chair

Oral Session - Plasma accelerators and ultra-short pulse interactions (15 minutes each)

2O1 Demonstration of electron acceleration by a beatwave excited plasma wave
Y. Kitagawa, T. Matsumoto, T. Minamihata, K. Sawai, K. Mima, K. Nishihara, H. Azechi, K. A. Tanaka, H. Takabe and S. Nakai

2O2 Initial laser-plasma formation
Y-H Chuang, H. Chen, S. Uchida and D. D. Meyerhofer

2O3 Interaction of intense fs light pulses with solid targets
P. Mulser

2O4 Results from high-intensity, 1 ps. laser-plasma interaction experiments
D. D. Meyerhofer, D. Bradley, Y-H Chuang, H. Chen, J. Delettrez, R. Epstein, P. Jaanimagi, S. Uchida and B. Yaakobi

2O5 Effects of nonlocal thermal and suprathermal electron transport in simulations of 1-ps laser pulse interaction
J. Delettrez, H. Chen, E. Epperlein, D. D. Meyerhofer and S. Uchida

2O6 Modelling of intense short pulsed laser experiments
J. M. Wallace, D. W. Forslund, J. M. Kindel, G. L. Olson and J. C. Comly

2O7 Continuum x-rays from solid density plasmas produced by the interaction of ultra-short laser pulses with matter
D. Umstadter, R. R. Freeman, H. Milchberg and T. McIlrath

2O8 Hot electron energy transport in picosecond laser-plasma interactions
S. Uchida, H. Chen, Y-H Chuang, J. Delettrez and D. D. Meyerhofer

2O9 Stimulated Brillouin scattering driven by a 10 ps pump
H. A. Baldis, H. C. Barr, D. M. Villeneuve, G. D. Enright, B. La Fontaine, J. E. Bernard, C. Labaune and S. Baton

2O10 Thomson scattering off tunneling ionization produced plasmas
W. P. Leemans, C. E. Clayton, K. Marsh and C. J. Joshi

Tuesday Evening, 7:30 PM, 10 July
A. Simon, Chair

Review Talk (45 Minutes)

General Situation in the Soviet Union
A. Rubenchik

Mixed Poster Session

2P1 Wake-field effect in laser-irradiated plasma
D. Teychenne, G. Bonnaud, and J. Bobin

2P2 Electron acceleration due to plasma waves driven by a frequency-swept beatwave
T. W. Johnston, P. Bertrand, A. Ghizzo, M. Shoucri, M. Feix, E. Fjalkow and J. P. Matte

2P3 Electron acceleration in a relativistic plasma wave
P. Mora

2P4 Simulations of possible sources of hot electrons in recent plasma beat wave experiments
S. C. Wilks, W. L. Kruer, A. B. Langdon, and J. M. Dawson

2P5 Radial expansion effects on the dynamics of exploding-foil targets
D. S. Montgomery, S. H. Batha, R. P. Drake, K. Estabrook, D. W. Phillion and B. A. Remington

2P6 Experimental scaling of low-gain processes in exploding-foil plasmas
S. H. Batha, D. S. Montgomery, R. P. Drake, K. Estabrook, D. W. Phillion and B. A. Remington

2P7 Steady coronal outflow from laser-driven gold disks
D. Ress and E. F. Gabl

2P8 Kinetic description of a shock wave in a high temperature plasma
M. Casanova, O. Larroche and J. P. Matte

2P9 Numerical analysis of Mach wave generation as a mechanism for stabilization of converging shock fronts in plasma
D. Mostacci, M. De Rosa, V. Palleschi, F. Fama, K. Kawai, E. Panarella, D. P. Singh and M. Vaselli

2P10 X-ray conversion processes for longer pulses
W. C. Mead, B. Bezzerides, S. V. Coggeshall, M. Cray, G. R. Magelssen, J. A. Cobble and A. A. Hauer

2P11 Producing high density plasmas with focused x-rays
L. B. DaSilva, R. W. Falcone, D. L. Matthews, P. Duffy and J. E. Trebes

2P12 Alternative geometries for producing line foci
D. M. Villeneuve, G. D. Enright and H. A. Baldis

2P13 XUV diagnostics of laser-irradiated cylindrical cavities
J. E. Balmer, B. Soom and R. Weber

2P14 Modelling of x-ray emission from high-Z doped laser-imploded capsules
C. J. Keane, B. A. Hammel, J. D. Kilkenny, R. W. Lee, C. L. S. Lewis, L. J. Suter and P. Bell

2P15 Modeling conversion efficiency experiments in gold-beryllium disks
S. H. Langer, D. R. Kania, R. L. Kauffman, H. N. Kornblum and F. Ze

2P16 Numerical studies of particle motions and generation of radiation in relativistic wave-particle interactions
R. Williams, C. Joshi, C. Clayton and T. Katsouleas

2P17 Laser produced plasma with large amplitude density modulation of controllable wavelength
M. Laberge and J. Meyer

2P18 Experimental study of backscattered light in the presence of filaments
P. E. Young, H. A. Baldis, K. G. Estabrook and W. L. Kruer

2P19 Bandwidth of scattered radiation in laser-plasma interactions
C. C. Chow, A. Bers and A. K. Ram

2P20 Nonlinear description of stimulated Brillouin scattering
W. Rozmus and J. Candy

2P21 Influence of ablation to critical surfaces distance upon Rayleigh-Taylor instability
A. Estevez and J. Sanz

2P22 Dynamics of neonlike lasers in exploding-foil plasmas
A. Fry, R. Walling, G. Shimkaveg, D. Fields, R. Shepherd, A. Osterheld, B. MacGowan, L. DaSilva, J. Scofield, T. Phillips, D. Matthews, R. Stewart, W. Goldstein, M. Rosen, C. Cerjan and R. London

Wednesday Morning, 8:30 AM, 11 July
A. Schmitt, Chair

Oral Session - Laser - plasma interactions I
(15 minutes each)

3O1 Status of the U.S. Inertial Fusion Program
G. J. D'Alessio

3O2 Long scale length interaction experiments on OMEGA
W. Seka, R. S. Craxton, R. Bahr, D. Bradley, P. Jaanimagi, J. Knauer, S. Letzring, D. Meyerhofer, S. Morse, R. W. Short, A. Simon, C. Verdon and J. M. Soures

3O3 Laser interaction studies with long-scale plasmas
T. Afshar-Rad, D. Desselberger, A. Giulietti, L. A. Gizzi, F. Khattak and O. Willi

3O4 Nonlinear wakefield generation and optical guiding of intense laser pulses in plasmas
E. Esarey, P. Sprangle, A. Ting and G. Joyce

3O5 Collective parametric instabilities of many overlapping laser beams with finite bandwidth
B. Bezzerides, D. DuBois and H. A. Rose

3O6 Filamentation insatability for multiple overlapping beams with finite bandwidth and ISI
D. F. DuBois and H. A. Rose

3O7 A kinetic theory of laser beam thermal filamentation in plasmas
E. Epperlein

3O8 Transverse modulation instability of counterpropagating waves and conical radiation
G. G. Luther, C. J. McKinstrie, and A. L. Gaeta

3O9 Filamentation of obliquely incident laser light in inhomogeneous plasmas
R. W. Short

3O10 Are supersonically collapsing filaments stable?
H. A. Rose and D. F. DuBois

3O11 Laser fusion to space and environmental research
A. Y. Wong

Wednesday Evening, 6:00 PM, 11 July
N. Delamater, Chair

Banquet
Business meeting - Roy Johnson, Chair
Review Talk (45 minutes)

"Hubble Space Telescope Projects"

Dr. John Clarke
Department of Atmospheric, Oceanic, and Space Sciences
University of Michigan

Thursday Morning, 8:30 AM, 12 July
R. Kauffman, Chair

Oral Session - X-ray diagnostics and x-ray lasers (15 minutes each)

4O1 Laser-matter interaction at intensities of 10^{12} W/cm^2 and below
S. R. Goldman, R. S. Dingus, R. C. Kirkpatrick, R. A. Kopp, E. K. Stover and R. G. Watt

4O2 Demonstration of frequency upshifting of electromagnetic radiation by a relativistic ionization front
R. L. Savage, Jr., C. Joshi and W. B. Mori

4O3 Fine-structure satellites and the temperature dependence of x-ray absorption lines in high-temperature plasmas
R. Epstein

4O4 Detailed configuration accounting opacities computed with statistical term structure
B. G. Wilson, J. R. Albritton and D. A. Liberman

4O5 Ne-like x-ray lasers from thick targets
T. Boehly, R. S. Craxton, R. Epstein, M. Russotto and B. Yaakobi

4O6 Dynamics of neon-like lasers in exploding-foil plasmas
R. Walling, G. Shimkaveg, D. Fields, R. Shepherd, A. Osterheld, B. MacGowan, L. Da Silva, J. Scofield, T. Phillips, A. Fry, D. Matthews, R. Stewart, W. Goldstein, M. Eckart, M. Rosen, C. Cerjan and R. London

4O7 High resolution x-ray laser linewidth measurements
D. L. Matthews, B. J. MacGowan, L. B. DaSilva, D. J. Fields, A. R. Fry, G. Shimkaveg, J. H. Underwood, P. J. Batson, and K. L. Chapman

4O8 Temperature determination of high-Z laser produced plasmas using K-shell spectroscopy
R. Shepherd, B. Young, G. Fletcher, D. Matthews, M. Eckart, R. Fortner, R. Stewart, A. Osterheld, R. Walling, W. Goldstein, Gar. Busch, and G. Charatis

Thursday Evening, 7:30 PM, 12 July
R. Berger, Chair

Discussion Session

Mixed Poster Session

4P1 A numerical study of x-ray emission from the central plasma in a low pressure spherical pinch
D. Mostacci, V. Molinari, K. Kawai and E. Panarella

4P2 Influence of the 1s2131'-1s^{2}21 satellite lines on density determinations from stark broadening analysis
N. D. Delamater, G. Charatis, C. J. Keane and B. A. Hammel

4P3 Development of a collective Thomson scattering diagnostic using the ion acoustic decay instability
K. Mizuno, W. Seka, R. Bahr, R. P. Drake and J. S. DeGroot

4P4 Subharmonic generation in large maplitude relativistic plasma waves excited by collinear optical mixing
W. P. Leemans, C. Joshi, C. E. Clayton and W. B. Mori

4P5 Acceleration of flyer plates by contained laser plasmas...recent experiments and simulations
R. A. Kopp and D. L. Paisley

4P6 Two-dimensional modeling of refraction effects in a plasma fiber waveguide
R. Rankin, C. E. Capjack. N. H. Burnett and P. Corkum

4P7 Non Maxwellian dlelectronic satellite spectra in picosecond laser interaction on aluminum
P. Audebert, C. Chenais-Popovics, J. P. Geindre, J. C. Gauthier, M. Chaker, J. C. Kieffer. H. Pepin and T. Auguste

4P8 The interaction of picosecond laser pulses with solid targets
V. A. Barrow, J. Edwards, G. Kiehn. R. A. Smith, and O. Willi

4P9 XUV gain measurements in a collisionally excited germanium plasma
G. D. Enright, D. M. Villeneuve, H. A. Baldis, J. C. Kieffer, H. Pepin, M. Chaker and P. R. Herman

4P10 Recent progress in the development of nickel-like x-ray amplifiers near the carbon K edge
B. J. MacGowan, L. B. DaSilva, D. J. Fields, C. J. Keane, D. L. Matthews, S. Maxon, A. L. Osterheld. J. H. Scofield and G. Shimkaveg

4P11 Electron energy distribution functions in neon-like x-ray lasers
J. P. Matte, R. Marchand, and Y. T. Lee

4P12 Short pulse collisionally pumped soft x-ray laser
H. *Milchberg*

4P13 Predictions of collisionally pumped cobalt-like x-ray lasers
A. L. Osterheld, R. S. Walling, W. H. Goldstein, and B. J. MacGowan

4P14 Measurement of line-coincidences in resonantly photopumped short wavelength lasing schemes
B. K. F. Young, R. L. Shepherd, A. L. Osterheld, Gar. E. Busch, G. Charatis, R. S. Walling, W. H. Goldstein. D. L. Matthews, M. J. Eckart, R. J. Fortner and R. E. Stewart

4P15 Time resolved x-ray monochromatic imaging of Al and Ge line focus plasmas
J. C. Kieffer, M. Chaker. H. Pepin, H. A. Baldis, G. D. Enright, and D. M. Villeneuve

4P16 Angular distribution of Raman forward scattering
W. L. Kruer, S. C. Wilks and A. B. Langdon

4P17 Resonant four-wave mixing in an unmagnetized plasma
C. W. Domier, N. C. Luhmann, Jr. and W. A. Peebles

4P18 Stimulated Raman forward scattering and the relativistic modulational instability of light waves in rarefied plasma
C. J. McKinstrie, L. Mu, M. Yu, and R. Bingham

4P19 Time/space-resolved spectroscopy of 2ω and $3/2\omega$ from laser irradiated thin foil plasmas
A. Giulietti. D. Batani. V. Biancalana, F. Bianconi, P. Chessa. I. Deha and D. Giulietti

4P20 Calculations of Langmuir wave K-spectra near quarter-critical density
L. V. Powers

4P21 Simulation of a laser-imploded gold-coated glass microballoon with a radiation dependent ionization model
M. Busquet, G. Schurtz, G. Colin de Verdiere

Friday Morning, 8:30 AM, 13 July
W. Mori, Chair

Oral Session - Laser-plasma interactions II
(15 minutes each)

5O1 Multi-frame interferometric study of a laser irradiated plasma in the presence of the two plasmon decay instability
J. Meyer and H. Houtman

5O2 Production of three-halves harmonic emission in laser-produced plasmas
P. E. Young

5O3 Pulsation of $3/2\omega$ and x-ray emission from ND laser produced plasmas

B. Luther-Davies, A. Rode and R. Dragila
5O4 Four-wave mixing and time-dependent phase conjugation in plasmas
E. A. Williams and M. V. Goldman
5O5 Absorption of powerful electromagnetic radiation by plasmas
E. Gavrilov, A. Rubenchik, and V. Shvets
5O6 Caviton burnout, the bump-on-tail electron velocity distribution, and fast ion beams
A. Simon
5O7 Observation and analysis of up and down-shifted stimulated Raman scattering in backward direction
C. Labaune, D. Pesme. H. A. Baldis and S. D. Baton
5O8 Experiments to measure low-gain processes in laser-produced plasmas
R. P. Drake, S. H. Batha, D. S. Montgomery, Kent Estabrook and B. A. Remington

ORAL SESSION 1

M. Cray, Chair

Energy Transport and Hydrodynamics

Studies of the First-Shock Effects in ICF Capsules*

S. V. Coggeshall, N. M. Hoffman, A. Hauer

Los Alamos National Laboratory

We present LASNEX calculations of shocks passing through directly-illuminated planar targets. Shock transit times, pressures and material adiabats as a function of laser intensity will be shown for a variety of materials. These materials include wetted foam or plastic over cryogenic DT, and solid Al. Incident laser intensities range from $\sim 10^{11} - 10^{14}$ W/cm^2. Studies of the effects of such shocks are relevant to the understanding of the "foot" portion of a pulsed-shaped, high-gain ICF capsule. Details of such pulse-shape experiments scheduled for the Los Alamos Aurora laser system will also be presented.

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

Hydrodynamic Modeling of NIKE Target Experiments

J. H. Gardner, J. P. Dahlburg, and M. H. Emery
Laboratory for Computational Physics & Fluid Dynamics

and S. E. Bodner
Laser Plasma Branch, Plasma Physics Division

Naval Research Laboratory, Washington, D. C. 20375

The NIKE KrF laser system is being designed and built at NRL to provide the U.S. with a go/no-go decision on an ignition-sized implosion facility. NIKE will be used to accelerate a flat foil to simulate the first few nanoseconds of the implosion of a thin, high-gain pellet shell. We hope to model all of the ablation physics of inertial fusion correctly, leaving out only the final spherical convergence effects. With echelon-free ISI optical smoothing[1], NIKE's peak-to-valley nonuniformity on target is expected to be *1-2* percent -- the same as required for a high-gain pellet. The foil will be illuminated with about the same mass-per-unit-area as a high gain pellet, and with about the same laser intensity as a high gain pellet ($\sim 3\times10^{14}$ W/cm^2). Pulse shapes will initially have only two simple steps, but eventually we hope to duplicate the actual pulse shape of a high gain pellet through the initial portion of the highest intensity.

Flat targets have two advantages in the near term for laser fusion: they have greatly improved diagnostic access, and, because the mass-per-unit-area can be larger, they better match some of the physics of high-gain pellets, without the associated preheat that occurs when one tries to scale down a pellet to smaller size.

The NIKE laser does however provide its own restrictions on the targets. The total beam energy will be less than *4* kJ on target, and the high-power portion of the pulse must be > *2* ns. The planar targets also place a restriction on the spot size and pulse duration: the distance and time that the foil can be accelerated is limited by two-dimensional edge effects. In general, for the energy of the NIKE system, the optimum pulse length is somewhat shorter than the five nanoseconds that would be preferred by the laser builders.

We will present target designs for the NIKE facility. We are proposing initially using plastic (CH) foils of about *60* μm thickness. This will give an in-flight-aspect-ratio of about 20 for the initial two-step laser pulse. The target thickness and laser intensity will also ensure that the effects of radiation preheat are properly included; we believe that this is important in the control of the Rayleigh-Taylor instability[2]. The foil acceleration should give us about 10 classical e-folds of this instability; this should be enough to test the predictions of reduced growth rate.

[1] R. H. Lehmberg & S. P. Obenschain, Opt. Comm. **46**, 27 (1983)
[2] J. H. Gardner, S. E. Bodner, & J. P. Dahlburg, Phys. Fluids B, *in press,* 1990

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THEORETICAL ANALYSIS OF HIGH DENSITY COMPRESSION OF PLASTIC SHELL TARGETS

K. Mima, A. Nishiguchi, H. Azechi, N.Miyanaga, H. Takabe, K. Nishihara, M. Nakatsuka, T. Jitsuno and S. Nakai

Institute of Laser Engineering, Osaka University
2-6 Suita, Osaka 565, Japan

Plastic shell targets of CD and CDTSi have been imploded by 0.53μm by GEKKO XII laser. Radial convergence ratios of the implosion were 20~ 30 for intial target aspect ratios of 20~50.

By the hydrodynamics simulation code 'HIMICO' which includes Fokker Planck electron heat transport package, the shell preheatings by high energy tail electrons and X-ray radiations are investigated. Simulations of the radiation preheating for Si doped plastic shell targets show that it is very sensitive to the atomic and radiation transport models.

As the second topic, presented is the imploded shell uniformity analysis in which Rayleigh Taylor mode amplitudes are evaluated by taking into account the experimental data for the irradiation laser uniformity and the target shell uniformity. Finally, the differences of experimental neutron yield and ρr from the 1 D simulation results are discussed.

Simulation of the Ablatively Driven Inner Surface Rayleigh-Taylor Instability.

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

Laboratory for Computational Physics & Fluid Dynamics
Naval Research Laboratory, Washington, D.C. 20375

In order (1) to investigate the fundamental physics of the ablatively driven inner surface Rayleigh-Taylor instability, and (2) to provide a vocabulary for the more complicated parallel study in convergent geometry, we first simulate the laser-driven collision of a pair of rectilinear targets in the presence of the ablative Rayleigh-Taylor instability on the laser-side target surfaces.[1] Conditions appropriate to high-gain inertial fusion pellets are chosen for the colliding-foil simulations reported, with 80 μm thick plastic [CH] targets accelerated towards each other from a separation distance of 650 μm by a 1/4 μm laser beam with an intensity of 3×10^{14} W/cm^2. Results from the colliding-foil study indicate that the unstable inner (non-irradiated) surface Rayleigh-Taylor [RT] and Richhtmyer-Meshkov [RM] growth is short but violent. Shock waves form and pass through the low density buffer material separating the targets, resulting in localized density jumps at the shock fronts. These density jumps are well-separated by low-density buffer gas from the target bulk at early times. During this period, the inner surface of the target bulk remains stable. This target profile continues until the approximately uniform linear acceleration of the targets is decreased in response to the pressure build-up in the inner region. As the acceleration of the target reverses, the inner sides of the targets become RT unstable and the RT growth on the laser sides is stabilized. Simultaneously with the compression, the density peaks between the targets are absorbed by the bulk of the targets, and some mixing of the transverse modes occurs. This mixing appears to arise as a consequence of the coalescence of the modes initially excited in the targets. Analysis from a series of colliding-foil simulations indicates that the dominant parameters which govern the collision dynamics are the amplitudes of the laser-side ablative instabilities at the time of the deceleration, and the peak deceleration pressure. In many cases, for a given pair of foils, the former can be extracted from the ablative model of Gardner and co-workers,[2] and an estimate for the latter can be obtained from relatively inexpensive one-dimensional simulations.

For the second part of our investigation, in the more relevant spherical geometry, we have developed a 2D, cartesian-grid spherical implosion version of our laser matter interaction code, *FAST2D*. We are applying this code to spherical implosion problems which parallel those described above, *viz* hollow CH shells with diameters of 650 μm, and inner surface instabilities driven by ablatively unstable long-wavelength laser side instabilities that are imposed at early times in the simulations. Areas of agreement and disagreement with the more easily dissected planar (non-convergent) results will be presented.

[1] J.P. Dahlburg, J.H. Gardner & M.H. Emery *submitted to Phys.Fluids* (spring, 1990).

[2] J.H. Gardner, S.E. Bodner & J.P. Dahlburg *Phys.Fluids B, to appear* (spring, 1990).

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

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Representing the Linear Growth of Fluid Instabilities in a Turbulence Transport Model†

Nelson Hoffman
Los Alamos National Laboratory

One of the strengths of transport theories for fluid turbulence is that they naturally describe the early, linear-growth stages of fluid instabilities under fairly general (though not all) conditions. Besnard, Harlow, and Rauenzahn[1](BHR) showed that their turbulence-transport model reproduces correctly the growth rate of turbulence kinetic energy in the linear Rayleigh-Taylor instability, for the case of a continuous interface (i.e., an interface for which the density scale length is much larger than the wavelength of any perturbation.) In the present work, we use an impulsive-pressure approximation to show that a k-epsilon model based on the BHR theory produces the correct initial magnitude of turbulence kinetic energy in the Richtmeyer-Meshkov instability (as given by Saffman and Meiron[2]), again for a continuous interface.

[1] D. Besnard, F. H. Harlow, and R. Rauenzahn, "Conservation and Transport Proper-ties of Turbulence with Large Density Variations," Los Alamos National Laboratory report LA-10911-MS (February 1987).

[2] P. G. Saffman and D. I. Meiron, "Kinetic energy generated by the incompressible Richtmeyer-Meshkov instability in a continuously stratified fluid," Phys. Fluids A **1**(11), November 1989, pp. 1767-1771.

† Work supported by U.S. Department of Energy

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COLLISION AND INTERPENETRATION OF PLASMAS CREATED BY LASER ILLUMINATED THICK FOILS: EXPERIMENT

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The interaction of two counterstreaming flows of ions with neutralizing warm electrons is a classic problem in plasma physics. Here we studied experimentally this interaction in a laser-produced plasma for which collisional interaction, specifically ion-ion collisions, is believed to be the dominant slowing down and thermalizing influence.[1] The experiments were designed as follows: Two 300 μm square slabs were placed facing each other 400 μm apart. One slab was magnesium (Mg) and the other was paralene with an aluminum (Al) dot placed in the center. The Al dot was 125 μm in diameter and 1 μm thick. The inside surface of each slab was illuminated with 0.53 μm laser light typically with an energy of 100 J and a pulse length between 0.7 - 1.3 ns. The light was focussed with two f/6 lenses to an approximately circular spot 300 μm in diameter at an angle of incidence to the target normal of 50 degrees. Diagnostics included time-integrated pinhole x-ray cameras, holographic interferometry, and a gated pinhole crystal spectrograph. From these measurements, we estimated the electron density, electron temperature, the Al ion density, and ion temperature in the region between the two slabs. The electron density attained 5-10 x 10^{20} cm^{-3} at the midplane between the slabs by 1 ns. The coronal electron temperature was 600-900 eV and was higher near the midplane. Early in the laser pulse, the plasmas interpenetrate, but by 1 ns the flows stagnate near the midplane.

[1] R.L. Berger, et al. 1986 Laser Program Annual Technical Report, Lawrence Livermore National Laboratory.

COLLISION AND INTERPENETRATION OF PLASMAS CREATED BY LASER ILLUMINATED THICK FOILS: INTERPRETATION

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The experimental results presented by Bosch et al. in a previous abstract are interpreted by using a combination of hydrodynamic and atomic physics models. The collision and interpenetration is modeled by using a special hydrocode OFIS[1] where each of the two ion flows is followed on its own Lagrangian mesh. The two interpenetrating fluids exchange momentum and energy through ion-ion and electron-ion collisions. The line and continuum emission is modeled rising the code RATION. Where needed, either experimental data or output from the OFIS are used. The modeling and the experiments both indicate that the flows stagnate by the end of the laser pulse. An observed increase in the electron temperature near the midplane is consistent with a transfer of some ion kinetic energy to electron thermal energy. Moreover, a broadening of the Ly_{α} line of aluminum (Al) near the midplane is consistent with an ion temperature 10-30 keV. There is evidence of complete interpenetration and no evidence of stagnation for the first 500 psec. Radial expansion of the Al plasma is observed and is partially responsible for differences between the model and the experiment.

[1]R.L. Berger, et al. 1986 Laser Program Annual Technical Report, Lawrence Livermore National Laboratory.

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THE EFFECT OF SMOOTHING BY SPECTRAL DISPERSION (SSD) ON BURNTHROUGH MEASUREMENTS USING THE OMEGA LASER SYSTEM

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We have previously reported[1] on the observation of anomalously high laser burnthrough rates in targets overcoated with a CH layer. This effect has been attributed[2] to mixing caused by the Rayleigh-Taylor instability which may be seeded by early time "shine-through" of laser light before plasma formation. We will show results from a new series of experiments, in which the incident laser has been smoothed by spectral dispersion (SSD). In addition to the spectrally dispersing x-ray streak camera used in the previous experiments, we will also present and compare data recorded using a imaging x-ray streak camera and a pair of multi-frame x-ray pinhole cameras.

1) D.K. Bradley, et al. 18th Anomalous Absorption Conference (1988).
2) J. Delettrez, et al. *Phys. Rev. A* (to be published).

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

Hydrodynamic Target Response to an ISI-Smoothed Laser Beam

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One of the critical elements for high gain target designs is the high degree of symmetry that must be maintained in the implosion process. The induced spatial incoherence concept[1] has some promise for reducing ablation pressure nonuniformities to $\approx 1\%$. The ISI method produces a spatial irradiance profile that is smooth on hydrodynamic time scales but undergoes large random fluctuations on picosecond time scales. We have incorporated a model for ISI into our FAST2D LMI Code, which accounts for the number of echelons, the size of the laser spot, the coherence time of the laser and the time delay induced by each echelon. The model produces a spatially and temporally randomly varying beam profile which is in good agreement with theory and experiment.

Transverse thermal conduction is effective at minimizing the long time average residual spatial structure inherent in an ISI-smoothed laser beam (for a typical spot size O(**1** mm) and 20 eschelons) as long as the sound transit time between the absorption region and the ablation region is greater than the ISI averaging time (100 - 200 t_c). Unfortunately, this necessitates a long scalelength, uniform plasma in the laser absorption region. This is difficult to achieve with a reactor-like laser pulse for which the laser intensity is $\leq 10^{13} W/cm^2$ for nearly 80 % of the temporal length of the pulse. We present the results of numerical simulations of several target/laser pulse designs which were investigated in an attempt to mitigate the impact of the initial shock structure stemming from the early temporal phase of the ISI laser beam. These designs include "foam-like" layers, high-Z barriers, shifting laser wavelengths and varying the angle of incidence of the incoming laser beam by incorporating a ray trace model.[2]

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

[2] J. Delettrez and N. Grandjouan, CECAM Report of Workshop on Rayleigh - Taylor Instabilities, Thermal Smoothing and Interactions in Laser Plasmas, p 24 (1988); and personal communication.

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OPTICAL PROBING DIAGNOSTICS FOR THE OMEGA UPGRADE

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Optical probing is considered for the diagnosis of the long-scale-length plasmas anticipated for the proposed 30-kJ, 351-nm upgraded OMEGA laser. Scale lengths at densities around or above one tenth critical are pertinent for the understanding of instabilities such as stimulated Raman scattering. The hydrodynamics code SAGE has been used to calculate representative profiles at different times during the shaped laser pulse, which is typically a ~ 5-ns foot pulse at low intensity followed by a $\lesssim$ 1-ns main pulse at high intensity ($\lesssim 10^{15}$ W/cm^2). The optical probing simulations are then carried out using the ray-tracing postprocessor code TRACER-3. Two probing techniques, interferometry and refractive image distortion (RID), are compared. Interferometry is limited by the maximum density accessible and the required short pulse duration. RID, which involves relaying the image of a grid through the plasma and analyzing the image distortions induced by refraction in the plasma, may be an attractive method for characterizing both global density scale lengths and nonuniformities in the plasma corona. Other probing techniques such as schlieren and shadowgraphy are discussed.

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REVIEW TALK 1

C. Labaune, Chair

Heavy Ion Fusion Versus Plasma Physics

A. Bruce Langdon

MIXED POSTER SESSION 1

Rayleigh-Taylor Experiments using Shaped Laser Pulses*

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The performance of inertial confinement fusion capsules is very sensitive to hydrodynamic instabilities in general and the Rayleigh-Taylor instability in particular. We are starting an experimental effort at the NOVA laser-fusion facility to study large growth Rayleigh-Taylor instability using shaped laser pulses. The initial targets will be made of fluorosilicon, and will have 50 μm wavelength preformed modulations over a range of initial amplitudes. Face-on radiography will be used to measure the opacity contrast from which we will deduce growth. Calculations of growth as a function of the relevant parameters and initial experimental results will be presented.

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

INSTABILITY GROWTH IN DIRECT DRIVE INERTIAL CONFINEMENT FUSION*

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Penetration of laser ablated layers can be analyzed in terms of the spectrum of unstable modes. Growth factors for the spectrum of modes are obtained by numerical integration of linearized hydrodynamic equations, derived by McCrory, Morse, and Taggart [*Nuclear Science and Engineering* **64**, 163 (1977)]. The onset of nonlinear saturation for this mode spectrum, and an estimate for growth in the saturated regime, are determined by a method developed by one of us [S. W. Haan, *Phys. Rev. A* **39**, 5812 (1989)]. Expansion to second order of the equations for the classical Rayleigh-Taylor instability reveals when coupling of shorter-wavelength modes becomes the dominant seed for growth of longer-wavelength modes. This effect is mitigated by mechanisms such as density gradient stabilization, which limit the growth of short-wavelength modes. Application of this methodology in simulation of directly-driven targets will be presented.

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

CALCULATED RADIOGRAPHIC SIGNATURES OF FLUID INSTABILITY GROWTH IN ICF IMPLOSIONS

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Fluid instability growth is important to the performance of laser-driven ICF implosions. Current numerical models (i.e. Lagrangian hydrocodes) can predict a number of the experimental observations, such as the trajectory of the imploding shell (indicating that the process by which the laser light is absorbed and converted into the kinetic energy of the shell is understood), but not the neutron yield, especially if the shell radius is many times larger than its thickness.[1] Fluid instabilities, such as Raleigh-Taylor and Richtmyer-Meshkopf, can both degrade the fuel compression and mix pusher material into the fuel, degrading yield. Experimental techniques for measuring these instabilities in convergent geometries, such as spherical implosions, are needed in order to determine how they influence the observed drop in yield.

X radiography may be the only way to directly measure the growth of these instabilities. We present an analytical technique used to predict radiographic images for an absorbing layer of uniform opacity but arbitrary shape (i.e. a uniform shell with a Gaussian bump). The effects of experimental parameters, such as bump size, shell velocity, and detector spatial and temporal resolution, on the radiographic image are discussed.

[1] See, for example, F. J. Marshall, et al., Phys. Rev. A 40, 2555 (1989).

An Alternative Inertial Confinement Scheme, the Spherical Pinch: a Numerical Evaluation

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The Spherical Pinch is a modified inertial confinement in that an independently generated central plasma is confined by mean of imploding shock waves launched from the edge of the spherical vessel. A numerical study has been conducted with realistic energy deposition assumptions to assess the neutron output from the reacting plasma. The results seem to indicate that sizeable neutron emission is to be expected, and that this is strongly dependent on the presence and correct relative timing of the two phenomena of the generation of the central plasma and the launching of the shocks.

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Aluminum Coated Optical Fibers As Infra-Red (1ω) Timing Fiducials For Synchronizing X-Ray Streak Cameras*

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Abstract

The timing fiducial system at the Nova Two-Beam Facility allows time-resolved X-ray and optical streak camera data from laser produced plasmas to be synchronized to within 30 picoseconds. The system makes use of Al-coated optical fibers inserted into apertures in the x-ray sensitive photo-cathodes. The coating acts as a photo-cathode for a low energy pulse of 1ω light that is synchronized to the main Nova beam. The use of the fundamental (1ω) for this fiducial pulse has been found to offer significant advantages over the use of the second harmonic (2ω). These advantages include brighter signals, greater reliability, and a higher damage threshold, allowing routine use without fiber replacement. The operation of the system will be described, and we will present the results of numerical simulations, undertaken to model the photo-electron production in the Al film, which give qualitative agreement with experimental data.

*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

THE GENERATION OF TUNABLE RADIATION USING AN UNDERDENSE IONIZATION FRONT

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It is shown that when a light pulse is incident upon a relativistic ionization front, the light pulse can be simultaneously upshifted in frequency and compressed in duration. If the front is overdense in its own frame then the incident frequency ω_i is upshifted by the factor $4\gamma_0^2$. We show that if instead the front is underdense then the frequency is upshifted by the factor $\left(1 + \frac{1}{4}\frac{\omega_p^2}{\omega_i^2}\right)$. The reflection and transmission coefficients are calculated for both the overdense and underdense cases. Examples are given to show that a relativistic ionization front can generate tunable radiation from millimeter to ultraviolet wavelengths.

This work is supported by DOE and LLNL.

Examination of X-Ray Conversion in Au:Be Dilution Experiments with the DDP Code.

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Abstract

During the summer of 1987, a series of experiments was performed at LLNL to study the conversion of 0.35 μm laser light into soft x-rays in high-Z materials. Opacity effects were examined by using targets made of gold, beryllium, and a mixture of gold and beryllium to vary the density of the strongly radiating gold in the target. All experiments were performed using a single arm of the Nova laser focused to an intensity of 5×10^{14} W/cm^2 onto disk targets. In addition to conversion efficiency measurements, these experiments produced high quality spatial, temporal, and spectral x-ray measurements of the irradiated disks. The Dynamic Detailed Configuration Package (DDP) code is a 1-D time-dependent hydro code which calculates x-ray emission using the non–LTE detailed atomic physics model DCA. Preliminary results of modeling the dilution expriments with DDP will be presented.

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UV Thomson Scattering from X-Ray Laser Plasmas

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The characterization of x-ray laser plasmas is important in order to optimize the the plasma conditions for lasing, as well as to minimize the energy requirements of the pump laser. We are using UV thermal Thomson scattering to obtain the electron and ion temperatures, as well as drift velocities in plasmas for which gain is expected to be present. The electron density is obtained independently by optical interferometry.

The plasmas are produced by a 1.06 μm 1 ns laser pulse with energies up to 150 J. The Thomson scattering diagnostic has a temporal resolution of < 50 ps, and a spatial resolution of < 80 μm. We will present preliminary data from low Z recombining plasmas (C, Al), as well as high Z (Ge, Ta, Yb) where collisionally excited gain is observed. The results are compared to X-ray line emission diagnostics, as well as to hydrodynamic computer modelling.

Monte Carlo Simulation of Complex Atomic Spectra for Opacity Calculations*

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The representation of complex spectra of ionized heavy atoms by the Unresolved Transition Arrays[1] model as gaussian distribution of line strengths has been very successful for the identification of emission spectra. However, it can be too crude an approximation for partly resolved arrays (PRAs) in absorption. The absorption of a continuous background by a PRA does not depend critically on the exact wavelengths and strengths of each line, as long as the partially resolved character is reproduced. We describe a Monte Carlo procedure for simulating PRAs and Rosseland means for arbitrary transition arrays. Results for ions of Fe will be presented.

*Work performed under the auspices of the U.S. Dept. of Energy by LLNL under contract W-7405-ENG-48.
**Permanent Address: Racah Institute of Physics, Hebrew University, Jerusalem, Israel.
[1] J. Bauche, C. Bauche-Arnoult and M. Klapisch, Advances At. Mol. Phys. 23, 131, (1988).

Soft X-ray generation from picosecond KrF Laser Pulses

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The generation of x-rays from plasmas produced by low energy picosecond KrF laser pulses is being studied with the aim of optimizing discharge KrF lasers for the production of soft x-rays. In particular there is considerable interest in the generation of 1 keV x-rays for x-ray lithography applications.

Measurements have been made using single pulse irradiation of various Z solid targets with laser pulses of energies up to 50 mJ and pulses durations of ~100ps. Quantitative conversion efficiencies have been determined using filtered PIN diode and vacuum x-ray diode detectors and these results will be presented.

It appears that optimum generation of shorter wavelength x-rays, $h\nu \cong 1$keV, may require the presence of a preformed plasma[1] and studies are being carried out to determine the effects of a preformed plasma on the conversion efficiencies. Such a situation would favour the utilization of a train of short laser pulses and would lend itself to the efficient extraction of a KrF discharge laser module by injection mode locking with a short seed pulse.

1. F. O'Neill and I.C.E. Turcu, Appl. Phys. Lett. **55**, 2603(1989).

SIMULATIONS OF BEAM SMOOTHING*

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We are constructing a 3-D time-dependent beam propagation code in Cartesian geometry to study filamentation of the incident laser light in underdense plasmas. This code will be used to guide and interpret the planned Nova experiments on beam smoothing. Initial results will explore the effect of beam smoothing schemes on ponderomotive filamentation with a saturable nonlinearity.

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* 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.

A Study of the Effects of Optical Smoothing on Ponderomotive Filamentation Using Selfconsistent Wave-Kinctics

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It is well known that the ray equations of geometric optics are Hamiltonian in form, i.e.:

$$\frac{d\mathbf{x}}{dt} = \frac{\partial\Omega}{\partial\mathbf{k}}; \qquad \frac{d\mathbf{k}}{dt} = -\frac{\partial\Omega}{\partial\mathbf{x}}; \qquad \frac{d\Omega}{dt} = \frac{\partial\Omega}{\partial t}$$

where (**x**,**k**) play the role of conjugate position and momentum. The function $\Omega = \Omega(\mathbf{x},\mathbf{k},t)$ is the dispersion relation and plays the role of the Hamiltonian. The total derivative in time implies a derivative following a ray trajectory. This ray description of the light field can be selfconsistenlty coupled to the bulk plasma motion[1,2]. When this is done ponderomotive force terms arise in the fluid equations for the plasma. Thus the momentum lost (or gained) by the light field due to refraction is correctly accounted for and gained (or lost) by the background medium.

The advantage of such an approach to the study of filamentation is that it utilizes the conceptual advantages of geometric optics while still allowing the background medium to be dynamic in time.

Here we report on recent attempts to apply such self-consistent models to the study of optical smoothing and its effect on filamentation. In particular we discuss how to model the effects of ISI drivers. With ISI laser beams the light amplitude varies on the coherence time of the laser ($\tau_c \approx 10^{-12}$ sec) while the plasma moves on the much slower sound time ($\tau_s \approx L/C_s \approx 10^{-9}$ sec, where L is a typical length scale and C_s the sound speed). We discuss how to numerically compute the rapid variations of the light field and the rapid plasma response in an efficient manner in order to then be able to follow the much slower evolution of sound waves or growing filaments.

1. E. R. Tracy and A. H. Boozer, Physics Letters A, **139** (1989)318.
2. A. H. Boozer (submitted to Physics of Fluids).

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Three-dimensional filamentation and optically smoothed light*

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Abstract

Recently, the SSD (Smoothing by Spectral Dispersion) optical smoothing method has been proposed[1] to allow broadband light in conjunction with glass lasers. Like the induced spatial incoherence (ISI) method[2], SSD uses spatial and temporal coherence to produce smooth illumination patterns by time averaging. Unlike ISI, SSD keeps some correlation between the time- and space-dependence to enable the frequency tripling. This correlation also creates some spatial frequency components that sweep across the plasma at velocities that may be resonant with the plasma sound speed. This resonance could possibly enhance filamentation[3] of these components.

We are using a three-dimensional laser-plasma propagation code[4] to simulate and compare both SSD and ISI beams under the same conditions to examine if they are equivalent. The results of these simulations will be presented.

1. S. Skupsky, R.W. Short, T. Kessler, R.S. Craxton, S. Letzring, and J.M. Soures, J. Appl. Phys **66**, 3456 (1989).
2. R.H. Lehmberg and S.P. Obenschain, Opt. Commun. **46**, 27 (1983); R.H. Lehmberg, A.J. Schmitt, and S.E. Bodner, J. Appl. Phys. **62**, 2680 (1987).
3. R.W. Short, Bull. Am. Phys. Soc. **34**, 2113 (1989); A.J. Schmitt, Phys. Fluids **B1**, 1287 (1989).
4. A.J. Schmitt, to be published; A.J. Schmitt, Bull. Am. Phys. Soc. **34**, 1880 (1989).

* *Supported by Department of Energy*

SIMULATION OF PONDEROMOTIVE FILAMENTATION IN LASER-PRODUCED PLASMAS

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The effect of nonlinear hydrodynamics on ponderomotive filamentation can be an important effect[1]. We discuss the development of two hydrocodes, one linear, the other nonlinear, with application to the study ponderomotive filamentation. In both codes the laser propagation is modeled by solving the paraxial wave equation.

The numerical scheme along with test problems for the hydrodynamics will be presented. We will compare the differences between linear and nonlinear hydrodynamics in order to determine the limits of the validity of the linear approximation.

1. J. P. Sheerin, Paper A4, 19th Annual Anomalous Absorption Conference, Durango, CO, (1989).

RELATIVISTIC SELF FOCUSING OF SHORT LASER BEAMS IN PLASMAS

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We numerically solve the stationnary equation for the laser beam profile including the mass increase of electrons caused by their relativistic motion in the laser wave, and the reduction of the electron density resulting from the ponderomotive expulsion of the electron from the laser channel. Compared with the work of Sun *et al.*[1] we look for higher order (ring) solutions in cylindrical geometry. We also look for plannar solutions (instead of cylindrical solutions), for a better comparison with computer simulations.[2]

[1] G.Z.Sun, E.Ott, Y.C.Lee, and P.Guzdar, Phys. Fluids **30**, 526 (1987).
[2] W.B.Mori, C.Joshi, J.M.Dawson, D.W.Forslund, and J.M.Kindel, Phys. Rev. Lett. **60**, 1298 (1988).

Collapse dynamics in 2-D Zakharov equations

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A 2-D wave coupling code (extended CHEOPS) has been designed to see in a rich but unnoisy context the time/space evolution of the coupling of a Langmuir wave to a ion-acoustic density modulation. No envelope assumption has been used and fully wave-like equations have been solved for the Langmuir wave and the ion-acoustic wave. Regards to a PIC code, the initial conditions can be well controlled and the computing time is not drastic; nevertheless, the fluid and kinetic-driven mechanisms such as the wave-breaking and the particle trapping are unmodelled. The simulations we performed have been focused on the pattern evolution of the Langmuir wave-packet.

Vlasov Simulation of Nonlinear Resonant Absorption and Wave Breaking

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The influence of kinetic effects on the resonant excitation of plasma waves is studied by solving numerically the (nonlinear) Vlasov equation for the capacitor model of resonant absorption. Thus the numerical noise inherent in particle simulations is avoided and a quantitative comparison with hydrodynamics can be made.

We find that in the resonance region the hydrodynamic description with an adiabatic law $p_e/p_0 \sim (n_e/n_0)^3$ is valid even in the case of strong damping by acceleration of electrons to several times thermal velocity (nonlinear Landau damping). Fast electrons are produced well below the wave breaking threshold derived by Coffey. The linear theory for the absorption remains valid for high driver fields ($I\lambda^2$ up to $10^{16}\mathrm{Wcm}^{-2}\mu\mathrm{m}^2$), although the plasma wave is strongly nonlinear and a large amount of the energy is carried by fast electrons.

We define wave breaking as destruction of the periodicity of the wave. The nonlinear Landau damping prevents the wave from reaching the hydrodynamic breaking amplitude outside the resonance region. Wave breaking occurs, when the mean electron velocity approaches the phase speed leading to trapping of large bunches of electrons. The threshold driver field is reproduced by the theory for a cold streaming plasma but with the group velocity replacing the flow velocity. If profile steepening is taken into account, the threshold light intensity for wave breaking to occur is $I_{wb}\lambda^2 \approx 10^{15}\mathrm{Wcm}^{-2}\mu\mathrm{m}^2$.

FREQUENCY UPSHIFTING AND CHIRPING OF SUB-PICOSECOND LASER PULSES VIA TIME DEPENDENT PLASMA DENSITY*

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We investigate a possible mechanism for producing large frequency upshifts and chirps on sub-picosecond laser pulses. Frequency shifts of a few percent along with spectral broadening, have already been experimentally observed when intense (10^{16} W/cm^2) femtosecond lasers are focussed into a gas cell, creating a plasma at the focus.[1] It may be possible, by choosing a certain laser intensity profile, to maximize this effect by having ionization occur over a number of laser wavelengths. This would create large plasma density gradients along the pulse, in both space and time, leading to upshift and modulation of the pulse. The result would be a frequency chirped pulse, where the central frequency has been upshifted. Comparisons of the model with the experiment, and considerations for future experiments, will be discussed. The 1- and 2-D PIC simulation results will also be presented.

1. M. W. Wood, G. Focht, and M. C. Downer, *Optics Letters*, **13**, 984 (1988).

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SUPPRESSION OF THE PEDESTAL AND PRE-PULSE IN A CHIRPED-PULSE-AMPLIFICATION LASER

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The pedestal (pre-pulse) associated with a chirped-pulse-amplification and compression (CPAC) laser is studied. This laser operates at 1053 nm with 1 ps duration and energies of a few hundred mJ. The pedestal has three sources: the non-linearly chirped part of the frequency spectrum introduced from the fiber, the low intensity, long duration temporal wings which go directly through the fiber without self-phase-modulation, and the phase modulation in the non-ideal amplifying system. The nonlinearly chirped part of the laser is suppressed by the gain-narrowing of the regenerative amplifier. The low intensity, long duration sidelobes are suppressed by a saturable absorber. The amplification system is improved by adjusting the line center to that of the chirped pulse out of the fiber and operating below saturation. Pre-pulse intensity contrasts exceeding 5×10^4 have been produced. The results of this work make possible the study of high-intensity ultra-short laser plasma interactions with a fiber-grating CPAC system.

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PRODUCTION OF HIGH CONTRAST SUB-PICOSECOND LASER PULSES FROM PULSE-COMPRESSED ND LASERS

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Pulse compressed lasers in general have much poorer energy contrast (ratio of main pulse to pre-pulse energy) than conventional fusion laser systems due to inherent limitations of the pulse compression process. Spectral filtering and/or non-linear polarization rotation in the optical fibre used to produce the frequency chirped pulses suitable for compression are normally used to improve the energy contrast. In this poster we describe two other techniques which are investigating for use in the ANU sub-psec laser system. These are firstly, contrast enhancement and pulse compression using group velocity dispersion during second harmonic conversion in KDP crystals; and secondly contrast enhancement using weakly coupled twin core optical fibre switches. The former process enables ≈300% power conversion during second harmonic generation and simultaneously a reduction in optical pulse duration from 1 to 0.25 psec. The latter provides contrast improvements of $\approx 10^6$.

Energy balance and transport in short gradient scalelength plasma

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Ultra Fast Science Laboratory, Univ. of Michigan, Ann Arbor, U.S.A.

We present experimental results obtained with the new one picosecond laser system of the Ultrafast Science Laboratory. The laser pulse, frequency doubled (λ = 0.53 μm), is focussed on plane solid targets to intensities up to 10^{16} W/cm^2. Diagnostics included an integrating sphere for absorption measurements, a multichannel X-ray spectrometer, an X-ray transmission grating and high resolution spectrometers. The energy absorption and transport (thermal and hot electrons) are characterized for various very short gradient scalelengths from multilayer targets data. The energy balance, including X-ray conversion efficiencies, will be discussed. A comparison with 1.06 μm data will also be presented.

Compression of Magnetic Flux by Laser Irradiation

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presented at the 20th Annual Anomalous Absorption Conference
Sugarloaf Resort, Traverse City , Michigan, U.S.A.
July 9 – 13. 1989

A numerical analysis is carried out for a magnetic flux compression scheme that exploits the fast rising nature of a laser pulse. In the proposed scheme, an axial magnetic field is initially established inside a cylindrical shell, which will then be driven radially inward by the laser ablation pressure acting at the surface of the cylinder. As the cylinder implodes rapidly inward, the magnetic field is compressed via the well-known ~ $1/R^2$ law. This scheme has been shown by recent modeling studies to be most suitable for the generation of highly concentrated magnetic pulses of rising speed faster than ~ *gigagagauss/μsec*. The present numerical study shows that it is indeed possible to achieve such magnetic pulses with the use of currently available laser facilities. The results of both perturbed and unperturbed calculations will be presented at the meeting for various implosion conditions. This work is supported by NFS under the Grant No. ECS-8818975.

ORAL SESSION 2

T. Johnston, Chair

Plasma Accelerators and Ultra-Short Pulse Interactions

Demonstration of Electron Acceleration by a Beatwave excited Plasma Wave

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Reported is the first simultaneous observations of a beatwave excited plasma wave and accelerated electrons. A laser with 10.6 and 9.57 μm wavelengths excites the plasma wave, when the plasma frequency equals the beatwave frequency. The plasma wave accelerates plasma electrons with initial energies less than 10 MeV to 20 MeV. The hydrogen plasma is produced by the same laser as that exciting the wave. The Stokes sideband measurement gives the wave amplitude $\delta n/n_0$ of 3 %. The experiment offers a possibility for the plasma beatwave accelerator.

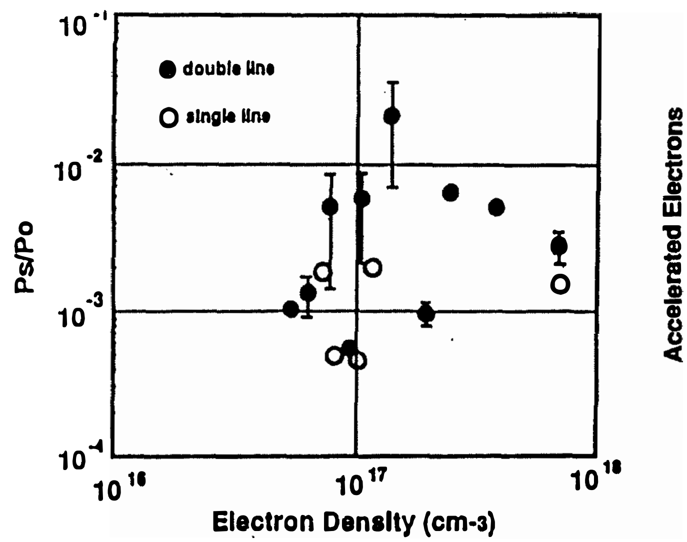

Fig. 1. Forward scattered Stokes sideband intensity at 11.857 μm divided by 10.6 μm pump intensity is plotted as a function of the electron density: Solid circles for double line and white circle for single line irradiation. Stray noise level is 10^{-3}.

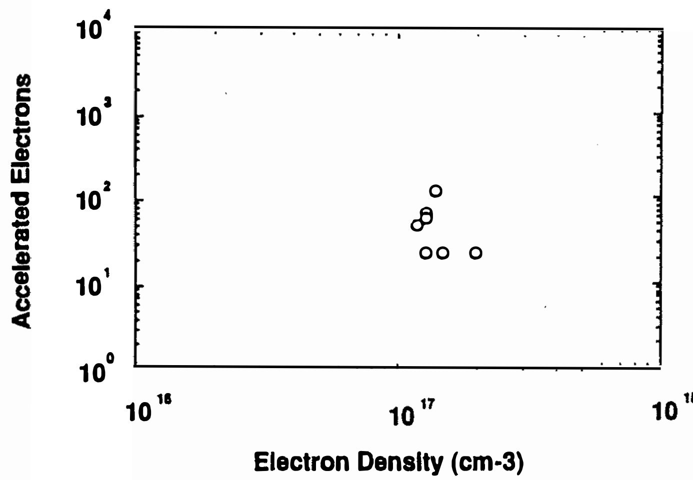

Fig. 2. Number of the high energy electrons (10 to 22 MeV) emitted into the ESM aperture versus the electron density with double line irradiation.

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INITIAL LASER-PLASMA FORMATION

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A chirped-pulse-amplification and compression (CPAC) laser is used to study breakdown and plasma formation in dielectric targets. The laser operates at 1.053μm with energies of a few hundred mJ. The pulse duration is as short as 1 ps when the pulse is fully compressed and can be partially compressed to provide a chirped pulse for target interactions. Due to the linear relation between time and wavelength, the transmitted (shine-through) and reflected spectra show temporal signatures of plasma formation. The plasma creation is also diagnosed with a 1 ps probe beam via Schlieren techniques. The probe split from the main laser pulse and frequency doubled. The CPAC laser system allows a wide variation in the characteristics of the interaction pulse. The spectra of the reflection and shine-through, the characteristics of the self-focussing tracks, and the plasma generation observed with the probe beam will be discussed.

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

Interaction of Intense fs Light Pulses with Solid Targets

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Femtosecond laser pulses are capable of producing very high light intensities at moderate pulse energies. In the presentation laser light absorption at flux densities of 10^{17} W/cm^2 and higher during the plasma formation and the plasma heating process is described. In the first stage multiphoton and collisional ionization dominate. Modifications of the inverse bremsstrahlung absorption occur due to ionization dephasing. In the second stage beam energy conversion is mainly by collisional absorption at normal incidence, and by resonance absorption at oblique illumination. Simultaneously strong electron heat conduction provides for plasma formation and heating in deeper layers of the solid not accessible to the laser light. The penetration depth of the laser beam is modified by the anomalous skin effect. The electron-ion collision frequency at the high laser intensities under consideration is determined by the oscillation energy of the electrons, rather than by their thermal motion. Although it reaches high values ($10^{14} - 10^{16}$ s^{-1}) all kinds of solid targets become strongly reflecting ($> 60\%$) due to the formation of electron densities largely exceeding those of solid state plasmas. Effects modifying the degree of absorption are briefly discussed.

RESULTS FROM HIGH-INTENSITY, 1 PS, LASER-PLASMA INTERACTION EXPERIMENTS

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Characteristics of the plasma produced by the interaction of a high intensity (> 10^{16} W/cm^2), 1 ps, 1.053 μm, laser pulse with solid targets are presented. Recent improvements in the laser system have reduced the pedestal (prepulse) to an energy of less than 0.1% of the main pulse with an intensity contrast of approximately 10^5. The plasmas produced by these pulses are diagnosed using an Ulbricht's sphere to measure absorption and charge collectors to measure the ion velocity distribution. EUV and X-ray emission from the plasma are observed using time-integrated spectroscopy, an x-ray streak camera with a temporal resolution of ~ 5 ps and filtered X-ray PIN diodes. The latter allow a measurement of the x-ray continuum emission. An optical probe beam is used to study the breakdown of the solid targets. The experiments have included various target materials and incident angles. Multi-layer targets allow a study of generation of suprathermal electrons, and electron and thermal transport in the plasma.

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

EFFECTS OF NONLOCAL THERMAL AND SUPRATHERMAL ELECTRON TRANSPORT IN SIMULATIONS OF 1-PS LASER PULSE INTERACTION

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We present the results of hydrodynamic simulations of 1-ps pulse interaction experiments carried out on the T^3 laser at the University of Rochester. Simulations carried out with the 1-D code LILAC, in which the absorption of the laser light at short scale lengths is calculated by solving the one-dimensional wave equation, consistently produced laser absorption fractions lower than those measured in the experiment.[1] We report on two attempts to bring the simulation results in line with those of the experiment: by including non-local transport of the thermal electrons and by postulating that resonant absorption is an important absorption mechanism. Resonant absorption is assumed to exist, even at normal incidence, due to the presence of defects on the target surface. We conclude that non-local thermal electron transport does not sufficiently increase the absorption fraction. The effect of the suprathermal electrons generated by resonant absorption on target behavior and the ability to diagnose these effects is discussed. Comparison with the charge collector current trace and K_α production from experiment is presented.

1) J. Delettrez *et al*, Paper E9, 19th Annual Anomalous Absorption Conference, 1989.

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

MODELING OF INTENSE SHORT PULSED LASER EXPERIMENTS*

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Short-pulsed ultra-high intensity lasers are being used increasingly to study the atomic physics of plasmas in the effort to create conditions suitable for X-ray lasing. To compliment the experimental results being obtained from the Los Alamos Bright Source[1], we are using a combination of hydrodynamic and particle simulation codes including atomic physics. We shall present results of two-dimensional particle simulations of the laser-plasma interaction, which include fully relativistic equations of motion, electron-ion scattering, an accurate inverse-bremstrahlung model, and a simple ionization-rate model based on detailed atomic physics calculations. We shall show comparisons of the simulations with experimental results from the Los Alamos Bright Source at intensities of $10^{17} Watts/cm^2$. Calculations at intensities of $10^{19} Watts/cm^2$, appropriate to the Bright Source II, will also be presented. We shall discuss the competition between collisional absorption, ionization, plasma-instability growth, and resonant absorption. Conditions under which collective plasma phenomena dominate incoherent processes will be outlined.

[1]J.A. Cobble, et al., Phys. Rev. A, **39**, 454 (1989).

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

Continuum X-Rays from Solid Density Plasmas Produced by the Interaction of Ultra-Short Laser Pulses with Matter

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A one dimensional fluid code is used to model the interaction of an ultra-short laser pulse with an Aluminum target. Pressure, mass density, ionization and expansion velocity are computed as functions of space and time. The effects of various assumptions on the plasma dynamics are compared. For instance, local thermodynamic equilibrium is found to agree with a collisional radiative model everywhere but in the expanded regions. Spitzer thermal conductivity is found to exceed a measured thermal conductivity by up to an order of magnitude. Expansion is comparable to diffusion in cooling the electrons. The plasma expands into the vacuum at approximately the ion acoustic velocity. The shortest pulses of continuum soft x-rays from recombination are obtained by maximizing the cooling of the electrons and ion stages after the absorption of the laser light. This is accomplished by adjusting the incident light intensity on target, and thus the peak electron temperature, relative to the ionization energies of the target electrons. The optimum maximum electron temperature is found to be 200 eV, half the ionization energy of the last L shell electron. Temperatures less than this optimum value do not maximize cooling of the electrons. Temperatures greater than this optimum value do not maximize cooling of the ionization stages.

HOT ELECTRON ENERGY TRANSPORT IN PICOSECOND LASER-PLASMA INTERACTIONS

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The interaction of intense 1 ps laser pulses ($I_L \lesssim 10^{16}$ W/cm^2) and solid targets is presented. In picosecond laser-plasmas, hot electron generation due to resonance absorption appears to be an important phenomenon in both energy absorption and burst x-ray pulse application. The hot electron generation is studied by using layered targets in which K_α emission is a signature of hot electrons and gives quantitative information about hot electrons. The investigation is supported by series of experiments using K-edge filtered x-ray detector array (PIN diodes or scintillators) to measure x-ray continuum spectrum and charge collectors for fast ion velocity distribution measurements and an integrating sphere for absorption measurements. Since target surface conditions have a significant influence on picosecond laser-plasma interactions, these experiments include coated or unpolished targets and preformed plasmas. Thin foil targets are used to study the role of heat conduction and electron transport from interaction region into bulk material.

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

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Stimulated Brillouin Scattering Driven by a 10 ps Pump

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National Research Council of Canada

C. Labaune, and S. Baton

Ecole Polytechnique, France

Stimulated Brillouin Scattering (SBS) pumped by a short pulse in a pre-formed long scale length plasma has been studied. The 1.06 μm laser pulse has a duration of less than 10 ps, with irradiations over a range of intensities up to 10^{16} W cm^{-2}. The short pump permits the study to be done in the absence of plasma hydrodynamics, as well as allowing for a limited number of e-folding growths. The pre-formed plasma (scale lengths from < 100 μm to > mm) was produced by a 2.5 ns, 1.06 μm pulse incident on thin foil CH targets. The target thickness and the timing of the short pulse allows a wide range of plasma conditions to be accessed. The range of plasma and laser conditions has allowed the study of backscattered light from below SBS threshold (thermal level), to saturation level, as well as the transition region between weak and strong coupling regimes.

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Direct obs of e⁻ plasma waves generated thru stimulated Compton scattering.

Thomson Scattering off Tunneling Ionization Produced Plasmas

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Abstract

We report on Thomson scattering spectra obtained by scattering off short wavelength ($2\ k_0$) driven plasma waves in two different plasma sources. The two plasma sources are a) a preformed arc-discharge plasma and b) a CO_2-laser produced plasma through tunneling ionization. The chosen scattering angle corresponds to the optimal phase matching angle for scattering off waves driven by SBS or SRS from a high intensity CO_2 laser. The two plasmas are characterized by significantly different electron temperatures. In the preformed plasma Te is a few eV whereas in the laser produced plasma Te is much higher and dependent on the polarization of the laser. Using classical tunneling theory one finds that linear polarization produces electrons with Te typically 50 eV while for circular polarization Te is around 1.5 keV, at laser intensities of a few times 10^{14} W/cm^2.

Experimentally it is observed that the scattered spectrum from a preformed plasma shows a narrow spectral feature that is attributed to SRS-waves. On the other hand, the scattered spectrum from a tunneling ionization plasma is broad. These latter spectra are believed to be characteristic of plasma waves driven in the Compton regime and are modelled taking finite $k\lambda_d$ effects into account .

This work is supported by D.O.E.

REVIEW TALK 2

A. Simon, Chair

General Situation in the Soviet Union

A. Rubenchik

MIXED POSTER SESSION 2

Wake-field effect in laser-irradiated plasma

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By means of a 1-D relativistic PIC code (Euterpe code) simulations, the plasma behaviour induced by the propagation of a short-pulse laser wave has been investigated. We focused on the features of the driven wake plasma wave. To reduce the computer-time consuming, a "high" electron density has been chosen, namely 0.001 to 0.01 n_c. With such a choice, we could make a systematic study of the influence of both the laser-pulse shape of the laser wave and the laser irradiance. We tried to apprehend the relativistic electron motion impact on the final pattern of the plasma wave and finally on the acceleration process applied to external bunches of electrons.

Electron acceleration due to plasma waves driven by a frequency-swept beatwave

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ABSTRACT

Earlier results[1] for the Rosenbluth-Liu relativistic plasma oscillator with a time-swept frequency resonance ("chirp") showed that the amplitude limit for a static frequency is easily exceeded with an appropriate chirp rate. We have tested this concept with a 1½ D Euler-Vlasov fluid code and found (compared with fixed-frequency drive results[2]) striking increases in the energies of accelerated electrons (p/mc went from ~ 5 to 10) together with significant changes in the spatially solitonlike behaviour.

1 J.P. Matte and F. Martin, Plasma Phys. and Contr. Fusion 30(4) 395-8 (1988).

2 P. Bertrand et al., Phys. Fluids B (to be published).

ELECTRON ACCELERATION IN A RELATIVISTIC PLASMA WAVE

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We study the acceleration of relativistic electrons in an electron plasma wave. Compared with previous calculations,[1] *i*) we include an inhomogeneous (lorentzian) enveloppe for the electron plasma wave, modeling the laser optics; *ii*) we include the finite emittance of the electron beam in a 3-D calculation. The results are used to optimize the parameters of the electron beam injected in the beat-wave experiment of Ecole Polytechnique.

[1] P. Mora, F. Amiranoff, J. Appl. Phys. **66**, 3476 (1989).

SIMULATIONS OF POSSIBLE SOURCES OF HOT ELECTRONS IN RECENT PLASMA BEAT WAVE EXPERIMENTS*

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Recent beat wave accelerator experiments at Osaka University (done by Y. Kitagawa) have reported the acceleration of electrons up to energies greater than 20 MeV. However, several key points in the experiment remain unexplained. Simple estimates on the minimum energy the electrons would need, in order to be trapped and accelerated by the beat wave, are in the 2-4 MeV range. The experiment relied on obtaining these electrons (that were to be accelerated) from the cold (100 eV) background plasma. By considering the nonlinear interactions between various instabilities (SRS and SBS), we propose a few possible mechanisms for the generation of MeV electrons for their experimental parameters. Self-consistent 1- and 2-D PIC simulations will also 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.

Radial Expansion Effects on the Dynamics of Exploding-Foil Targets

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Exploding-foil targets are being used to create long-scale-length (>2.5 mm), low-density ($n_e/n_c \sim 1/20$ for 527-nm) plasmas in which low-gain processes can be studied. The plasma is formed by irradiating 2-μm CH foils, from both sides, with 15 kJ of 351-nm light focussed to a 950-μm diameter spot. Initial results indicate that the size and shape of the target has a large effect on the temporal evolution of the peak electron density. These effects become readily apparent halfway through the 2-nsec-square laser pulses when the peak electron density has fallen below $n_c/10$, and are attributed to radial expansion of the target. Further experiments will be performed with three different target shapes. The first, or "ribbon," target is 1.5 times the laser spot diameter in width and 5 times as tall. The second, or "infinite," target is at least 5 times the spot diameter in all directions. The third, or "dot," target is circular and has a diameter which is twice the spot size. The dot target is supported on a sheet of 800-Å-thick formvar. Measurements of the plasma evolution as a function of target size and shape will be presented and compared to 2-D *LASNEX* calculations.

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Experimental Scaling of Low-Gain Processes in Exploding-Foil Plasmas

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Light produced by the interaction of a high-intensity probe beam with a long-scale-length, low-density plasma, was spectrally and temporally resolved. Evidence for forward and backward stimulated Raman scattering, as well as for backward stimulated Brillouin scattering, will be presented. Trends in the data, as the pump-laser intensity is varied, will also be discussed.

The plasmas were created by irradiating 2-μm-thick CH foils with up to 15 kJ of 351-nm laser light in a 2-nsec, constant intensity pulse. Each of the seven preform beams was focussed to a 950-μm spot. The plasma was probed with 527-nm laser light, which had a maximum intensity of 4×10^{15} W/cm^2 in a 200-μm spot, after the peak density in the preformed plasma had decayed to about $n_c/20$. At that time, the parabolic density profile had a full width at half maximum of 3 mm. The critical density was 4×10^{21} cm^{-3} and the electron temperature was approximately 1 keV.

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Steady Coronal Outflow from Laser-Driven Gold Disks

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We have observed a steady-state coronal-plasma outflow in both experiments and calculations with laser-driven gold disks. Analytical calculations of one-dimensional isothermal expansions in cylindrical and spherical coordinates admit steady-state solutions, as well as the familiar self-similar solutions. Here we report experimental electron-density profiles that qualitatively demonstrate the expected transition from self-similar to steady-state behavior, but their detailed behavior is not a good match to the analytical result. Furthermore, one-dimensional (quasi-spherical) LASNEX calculations overestimate the observed steady-state plasma-density profile. Current efforts aim at elucidating the cause of the discrepancy through additional two-dimensional LASNEX modeling.

KINETIC DESCRIPTION OF A SHOCK WAVE IN A HIGH TEMPERATURE PLASMA

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In some implosion experiments,[1] finite mean free path effects are expected to occur so that a fluid description for modelling such processes is no more valid. Particularly, the usual expressions for ion viscosity and thermal flux may be questioned. Furthermore, non-Maxwellian effects could modify the usual nuclear reactivities[2] or induce some plasma instabilities.[3]

In order to investigate this problem from an elementary point of view, we have studied the structure of a planar shock wave in a high temperature plasma, neglecting radiative effects and nuclear reactions. More precisely, a time-dependent Fokker-Planck equation for ions has been numerically solved to study the central region of the shock, referred to as the ion shock,[3,4] where non-Maxwellian effects are expected to be strong. For the collision term, we use a direct differencing scheme without the help of Legendre polynomials, allowing large deviations from the standard Maxwellian.

First results obtained from this code show that strong deviations from thermodynamic equilibrium occur in the ion shock, indeed leading to an ionic heat flux and viscosity much larger than the classical values.

[1]T. Yabe, K.A. Tanaka, Las. Part. Beams 7, 259 (1989)
[2]T. Nishikawa, H. Takabe, K. Mima, Jpn. J. Appl. Phys. 28, 2004 (1989)
[3]K. Abe, G. Sakaguchi, Phys. Fluids 28, 3581 (1985)
[4]K. Abe, Phys. Fluids 18, 1125 (1975); M.S. Greywall, Phys. Fluids 18, 1439 (1975)

Numerical Analysis of Mach Wave Generation as a Mechanism for Stabilization of Converging Shock Fronts in Plasma

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In extensive experimental work conducted in recent years [1,2], Mach wave generation has proven to be a very effective mechanism in smoothing out and stabilizing a converging shock front generated as several independent shocks. Whereas extensive theoretical work has been done to determine under which conditions this phenomenon occurs, the results are not easily confronted with the experiments, due to intrinsic diagnostic difficulties. A case in point is the correct determination of the critical angle for the onset of Mach wave generation in the interaction of two strong spherical shocks [3]: recently, a theoretical study has been conducted that contradicts the usual lore on the subject [4], and it would be most interesting to be able to check this theory against accurate measurements. To this purpose, numerical simulations have been carried out using a 2-dimensional, Lagrangian hydrodynamics and heat transfer code. The results confirm the new theoretical findings and the need for careful, more accurate investigation of Mach wave generation.

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[1] - M. A. Harith *et al.*, J. Phys. D.: Appl. Phys. **22**, 1451, (1989).
[2] - M. De Rosa *et al.*, "Mutual Interaction of Spherical Shock Waves in Air: Mach Wave Generation", submitted to *Optics Communications* 1990.
[3] - M. A. Harith *et al.*, "Shock Waves Interaction and Mach Waves Production in Air", in Proceedings of the XIX International Conference on Phenomena in Ionized Gases, Belgrade (Yugoslavia), July 10-14/1989.
[4] - M. De Rosa *et al.*, "Derivation of Critical Angle for Mach Reflection for Strong Shock Waves", submitted to *Europhysics Letters* 1990.

X-ray Conversion Processes for Longer Pulses†

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We present simulations predicting the behavior of x-ray conversion processes under expected conditions of Aurora laser irradiations. Aurora will access longer pulses than previous systems, and should produce conditions relevant to the pulse "foot" of higher-energy, indirect-drive targets. We examine the plasma evolution at 0.248 μm wavelength for pulse lengths up to 5 ns, energies of 1-5 kJ, and intensities of order 10^{14} W/cm^2. We expect large hydrodynamic excursions, gentle plasma gradients, effective collisional absorption, and high x-ray conversion efficiencies. We assess plasma expansion and lateral heat flow for targets both smaller and larger than the laser spot. We compare the calculated conditions and dynamics with those obtained previously on Novette.[1] We present plans for and the current status of initial Aurora gold disk irradiations.

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

[1]W. C. Mead, E. K. Stover, R. L. Kauffman, H. N. Kornblum, and B. F. Lasinski, Phys. Rev. A **38**, 5275 (1988).

Producing High Density Plasmas with Focused X-rays*

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Abstract

Using a section of a gold coated ellipsoidal mirror we have begun a series of experiments to produce high density plasmas with x-ray radiation. In our work x-rays generated by a laser irradiated gold target are collected and focused onto an isolated target. The mirror intercepts a solid angle of ~ $5x10^{-3}$ sr and images the source with a 1:1 magnification. The x-ray spectrum delivered to the secondary target is centered at ~500-600 eV and has a spectral width of ~400 eV. In preliminary experiments performed on the NOVA Two-Beam Facility we have achieved x-ray fluxes of 800±100 J/cm^2 when irradiating a gold target with 3.5 kJ of 0.53 μm laser light in a 1 ns pulse. Experiments are now ongoing to determine the plasma conditions created with this facility. Details of these measurements will be presented.

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

Alternative Geometries for Producing Line Foci

D. M. Villeneuve, G. D. Enright and H. A. Baldis

National Research Council of Canada

Focusing a laser beam into a long narrow line is necessary for generating plasmas for x-ray laser purposes. All current methods utilize stigmatic lens or mirror arrangements which shift the focal plane of one axis relative to the other axis. These methods have several disadvantages: (1) the near-field pattern of the beam is impressed along the line axis; (2) even a perfectly uniform beam profile results in higher intensity in the center of the line compared with the ends. These methods produce a uniform line focus only for a perfect rectangular beam.

One alternative method was tried, utilizing what has been named a segmented edge array, SWA. This divides the beam into 10 strips which are individually aimed on the line focus. This technique improves the uniformity of illumination along the line by averaging the contributions from each of the 10 strips. Several problems in the initial design became apparent, particularly those due to coherence effects. Ways of improving the initial SWA design will be discussed.

XUV DIAGNOSTICS OF LASER-IRRADIATED CYLINDRICAL CAVITIES

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Laser irradiation of cylindrical cavities has attracted considerable interest in the context of soft x-ray laser experiments, where the confined plasma may act as an x-ray waveguide.

In our continuing experiments, 300 µm diameter cylindrical cavities of Al and Cu were irradiated at up to 10^{14} W/cm^2 with 1.05 µm/80 ps laser pulses directed through a longitudinal entrance slit. Off-center slits were used to reduce direct reflection losses. The locations of plasma ablation observed by time-resolved x-ray pinhole photography are shown to coincide with the locations of (multiple) reflections of laser light inside the cavity obtained from ray tracing calculations.

Time-resolved XUV spectra in the 10-20 nm range from planar targets of Be, C, and Al and from Al microtubes were taken with a flat-field spectrograph coupled to a XUV/soft x-ray streak camera. The spectra show a high degree of complexity which is due, in part, to the presence of higher orders of the diffraction grating. The insertion of gold mirrors used at a grazing angle of 10° to suppress the higher orders is shown to facilitate the analysis of the spectra considerably.

Modelling of X-ray Emission from High-Z Doped Laser-Imploded Capsules,* C.J. Keane, B.A. Hammel, J.D. Kilkenny, R.W. Lee, C.L.S. Lewis, L.J. Suter, and P. Bell, Lawrence Livermore National Laboratory, Livermore, CA 94550- Modelling of spectra obtained from deuterium filled capsules (seeded with high Z impurity gases) imploded by the Nova laser will be presented. K-shell emission in the 3 keV-4 keV region from argon seeded capsules has been used as a diagnostic of both fuel density (through line broadening) and fuel temperature (through line ratios). While this has proven to be a reliable technique, in future higher density experiments more advanced spectroscopic diagnostics operating at higher photon energy will be required due to the larger expected pusher optical depth. Accordingly, we have been examining the line broadening of L-shell lines in Ne-like xenon (E~4.5-6.5 keV) as a fuel density diagnostic. In this paper, line broadening calculations for both argon and xenon will be presented. In addition, first results of simulations of these plasmas using a recently developed spectroscopy postprocessor code will be discussed.

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

MODELING CONVERSION EFFICIENCY EXPERIMENTS IN GOLD-BERYLLIUM DISKS*

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A series of disks, varying from pure beryllium to pure gold, has been illuminated by 1 ns flat topped pulses of 3ω light at intensities of ≈$5x10^{14}$ W/cm^2 on the NOVA laser. This paper compares LASNEX models to the experimental data. Time integrated M-band spectra have been measured from both the front and back sides of a disk on a single shot. This data provides a probe of the emission in the hot ablated plasma and the absorption in the cold unablated plasma, and thus provides a check on LASNEX's ability to calculate emission and absorption in two different regimes. The optical depth of the slab varies as a function of the gold concentration, so this data also provides a check on the radiation transport modeling in LASNEX. The time dependence of the X-rays from the slab was measured in several spectral bands. Default LASNEX models predict that the X-ray intensity should closely track the laser intensity, while the data shows the X-ray intensity increasing much more slowly than the laser intensity. We present models that attempt to explain this effect. We conclude with a summary of the areas in which the models are in good agreement with the data, speculate about the cause of discrepancies in other areas, suggest future experiments, and indicate how our results relate to ICF experiments.

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

Numerical Studies of Particle Motions and Generation of Radiation in Relativistic Wave-Particle Interactions

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The problem of radiation emission by relativistic electrons while drifting transversely through a relativistic plasma wave has been studied using numerical techniques in 3 dimensions. The frequency spectrum, $dI/d\omega$, and angular distribution, $dI/d\Omega$, have been calculated from the velocity and acceleration of the electron along its trajectory. The results have been extended to many electrons to model a short pulse (bunch) of electrons, and beam emittance has been included. We discuss the application of these results for wave/electron beam diagnostics as well as for a source of spontaneous radiation.

This work is supported by D.O.E.

Laser Produced Plasma with Large Amplitude Density Modulation of Controllable Wavelength

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For a variety of laser-matter interaction studies (eg. filamentation, caviton collapse) it is desirable to produce plasmas with regular density variations of large amplitude and controllable wavelength. We have produced such plasmas by irradiating either ruled relief or lithographically produced gratings with a 6 ns ruby laser pulse of 10^{10}W/cm^2 intensity in the line focus. Gratings of constant wavelength λ in the range from 6 μm to 35 μm as well as chirped gratings with $3\mu m \leq \lambda \leq 10.6\ \mu m$ are investigated by studying the expansion of the plasma above the gratings using interferometry and shadowgraphy. The results are compared with computer model predictions. The plasma is found to be modulated with $\delta n/n \simeq 8\%$. By irradiating such a plasma with high intensity CO_2–laser radiation it can be used to accelerate charged particles.

Experimental study of backscattered light in the presence of filaments*

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Abstract

We have experimentally investigated the connection between parametrically scattered light and the presence of filaments in interactions between 1.06 μm laser light and a preformed plasma. Using a previously developed technique[1,2], we are able to diagnose the presence of filaments and change the filamentation threshold at a given laser intensity by varying the wavelength of the intensity perturbation imposed on beam spatial profile. Backscatter signal levels are compared, with and without filaments over a range of laser intensities below 5×10^{14} W/cm^2. Laser light scattered by the stimulated Brillouin instability is time and wavelength resolved, with an S-1 streak camera used as the detector. Laser light scattered by the stimulated Raman instability is time resolved, but wavelength-averaged over a spectral band from 1.4 to 1.6 μm; a fast pyroelectric detector is used as the sensing element and it is able to detect scattered light levels down to 10^{-6} of the incident laser power. The experiment shows no increase in parametrically-scattered light levels when filaments are detected with the optical probe beam. The theoretical implications of this result will be discussed.

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

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

[1] P. E. Young, *et al.*, Phys. Rev. Lett. **61**, 2336 (1988). [2] P. E. Young, *et al.*, Phys. Rev. Lett. **63**, 2812 (1989).

BANDWIDTH OF SCATTERED RADIATION IN LASER-PLASMA INTERACTIONS

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Recent experimental techniques allow measurements of the bandwidth of scattered radiation in laser-target experiments. Although nonlinear effects will certainly play an important role in determining this bandwidth, particularly at large incident laser power densities, an analysis based on linear, parametric instability theory in three dimensions has not yet been carried out. We have made such calculations for SRS and SBS using the three-dimensional, time-asymptotic Green's function description of these parametric instabilities. We show that, even within linear theory, a finite bandwidth in the scattered EM wave will naturally arise. In the forward direction two separate bands will appear, which we label by band A and band B. Depending on the scattering angle the bands will either overlap or be separated. In the backward direction band B will disappear. Band A always has a much higher linear growth rate than band B. In addition, Band A will be sharply peaked about the frequency of the scattered light wave while band B remains fairly flat. Both bands are wider for forward scattering than backward scattering. In the SRS case the width of band A spans two orders of magnitude from the forward to the backward direction. The range for SBS is a little less than an order of magnitude.

Research is supported in part by LLNL subcontract B108475, and DOE Contract No DE-AC02-78ET-51013.

NONLINEAR DESCRIPTION OF STIMULATED BRILLOUIN SCATTERING

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Evolution of stimulated Brillouin scattering is studied using 1-D fluid model accounting for the complete nonlinear description of sound waves. The effects of electron inertia have been neglected. The light propagation is described in adiabatic approximation leading to the boundary value problem for the vector potential. Similarly evolution of the electrostatic potential associated with sound waves is given by the boundary value problem.

Numerical solutions will be discussed in various range of parameters. The role of sound-wave steepening, harmonic generation and Landau damping will be analyzed.

INFLUENCE OF ABLATION TO CRITICAL SURFACES DISTANCE UPON RAYLEIGH-TAYLOR INSTABILITY

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Abstract.- The Rayleigh-Taylor instability is studied by means of a slab model, considering the influence of the slab thickness and ablation to critical surface distance upon the instability growth rate. In order to determine this, boundary conditions at the corona have to be used. Magnetic effects are considered.

Stabilization occurs for a certain perturbation wavenumbers region.

Dynamics of Neonlike Lasers in Exploding-Foil Plasmas*

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We report on recent neonlike XUV laser experiments at the NOVA 2-Beam Facility at Livermore. Our targets were primarily thin foils (< 2000 Å) of germanium or silver on 1000 Å plastic backing irradiated by 0.53 μm light. We used germanium (Z=32) as the focus of an overionization study. We had expected to strip the germanium ions well past the neonlike ionization stage and effectively terminate the lasing. Instead, for the highest intensity shots the neonlike lasing became weaker and shifted in time to the recombination phase of the plasma. This late time behavior is observed for NOVA laser intensities near 4×10^{14} Watts/cm^2. A new timing fiducial on the streaked spectrographs gives an absolute determination of both the time history of the XUV lasing spectra and the spontaneous x-ray spectra relative to the incident 500-ps Gaussian NOVA laser pulse. We hope by correlating these spectra to understand the change in dynamics of the neonlike lasing with the charge state history. We also achieved particularly strong lasing in neonlike silver (Z=47) at 99 Å. The gain coefficient appears to be as high or higher than for any other neonlike ion to date. Along with our more conventional 500-ps experiments, we are exploring short pulse (20-ps) laser irradiation of targets as additional neonlike recombination experiments.

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

ORAL SESSION 3

A. Schmitt, Chair

Laser - Plasma Interactions 1

STATUS OF THE U.S. INERTIAL FUSION PROGRAM

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During 1987 and 1988 several landmark experiments were performed by a number of participants in the U.S. Inertial Confinement Fusion Program. As a result, the Department of Energy Program Office (Inertial Fusion Division) held a four day classified Target Physics Review in November, 1988 to assess physics progress. The review panel consisted of seven independent experts with backgrounds in plasma physics. The unclassified version of the reviewers report became available in early 1990. A principal finding of the review is that recent experiments have demonstrated the physics to validate the basic concept of inertial confinement fusion. This represents the achievement of the major initial goal of the program, demonstration of the scientific feasibility of ICF. Subsequently, a National Academy of Sciences Review of the ICF Program was undertaken in late 1989. In its January, 1990 Interim Report, the NAS Committee concluded among other things that there was a high level of science and technology in the ICF program, and it made several programmatic and budgetary recommendations. These recommendations, if implemented, will have a strong impact on the direction of plasma physics research within the ICF program for a long time to come. Finally, in early 1990, the Secretary of Energy initiated a Fusion Policy Advisory Committee whose general purpose is to define a coherent fusion policy for the U.S. This Committee's recommendations are expected to have a definitive role in determining the role of ICF as a potential long term energy option for the U.S. Both the NAS and FPAC final reports are due in September, 1990.

LONG SCALE LENGTH INTERACTION EXPERIMENTS ON OMEGA

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Long scale length interaction experiments on OMEGA will be initiated shortly. The goal of these experiments is to produce plasmas with scale lengths near 1 mm and temperatures $\gtrsim$ 1 keV, and irradiate these plasmas with a high-intensity beam at ~ 10^{15} W/cm^2 to study the effect of beam smoothing techniques such as SSD on parametric instabilities.

The background plasma is formed by 8 primary plasma-producing beams which irradiate a mass-limited target (~ 300 μm diameter, 4-8 μm thick CH) symmetrically from two sides at intensities of $\leq 6 \times 10^{13}$ W/cm^2 (60 J, 0.7 ns, 351 nm). Once the plasma has expanded somewhat another 8 secondary heating beams are turned on with a delay of ~ 0.6 ns. These beams are incident at steep angles to the initial target surface, but are intercepted well by the expanded plasma and they are thus effective in maintaining the electron temperature nearly constant over a period of ~ 0.6 ns. These beams do not influence the hydrodynamic expansion noticeably. The transverse dimensions of this background plasma are approximately 600 to 800 μm, while the longitudinal dimensions are approximately 20 to 30% longer. These estimates of the background plasma conditions were obtained using the 2D hydrodynamic code SAGE.

The interaction beam is another one of OMEGA's 24 beams. It is tightly focused using a distributed phase plate of larger cell size than those on the plasma-forming beams. The intensity of this beam is expected to be well above all the usual parametric instability thresholds except for convective stimulated Raman scattering.

This paper will present results of experiments in progress.

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

LASER INTERACTION STUDIES WITH LONG-SCALE PLASMAS

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An experimental campaign is in progress at SERC Central Laser Facility of Rutherford Appleton Laboratory in order to study the interaction of powerful laser beams with long scalelength preformed plasmas simulating the corona of fusion targets. Results obtained so far gave interersting information including anomalous Brillouin and Raman spectra [1], direct observation of filamentation and whole beam self focusing [2], reduction of Brillouin, Raman and filamentary instabilities after beam smoothing [3].

A new experiment has been performed recently; it was mainly devoted to measure the dependence of Brillouin backscattering on laser irradiance, homogeneity of the preformed plasma and uniformity of the interacting beam. Four green ISI laser beams were used to produce the preformed plasma, while the interacting beam was infrared (1.053μm) either coherent or smoothed by ISI. Incident and backscattered laser energies were measured with calibrated calorimeters. Additional diagnostics included visible and X-ray time resolved spectroscopy, optical probing and multiframe 200ps-gate X-ray imaging. The latter technique allowed to observe the uniformity of the preformed plasma and to study X-ray emission during the interaction.

The preliminary data analysis shows that the backscattering level is very sensitive to the plasma homogeneity and beam uniformity. The "quality" of the interaction is greatly improved by beam smoothing, even if some extraordinary events of whole beam self focusing have been observed with smoothed beams and uniform plasmas, as shown from the evolution of the X-ray emitting region during the interaction.

[1] O.Willi et al., Opt. Comm. **70**, 487 (1989)

[2] S.E.Coe et al., Opt. Comm. **73**, 299 (1989)

[3] S.E.Coe et al., Europhys. Lett. **10**, 31 (1989)

Nonlinear Wakefield Generation and Optical Guiding of Intense Laser Pulses in Plasmas*

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A nonlinear theory of intense laser–plasma interactions is formulated using relativistic fluid theory. Under the quasi–static approximation, a set of coupled equations may be derived for the electrostatic potential of the plasma and for the vector potential of the laser field.[1] The quasi–static approximation assumes that the laser field does not significantly evolve during the time it takes the plasma electrons to transit the laser pulse. The resulting set of coupled equations is fully nonlinear and is valid for laser fields of arbitrary intensity and polarization. This model may be used to describe[1] i) generation of nonlinear plasma waves (wakefields), ii) optical guiding of laser pulses in plasmas, iii) excitation of coherent harmonic radiation and iv) frequency shifts induced in laser pulses by plasma waves or ionization fronts.

As a short, $\tau_L \simeq 2\pi\omega_p^{-1} \simeq 1$ ps, high power, $P \geq 10^{12}$ W, laser pulse propagates through a plasma, its ponderomotive force nonresonantly generates large amplitude, $E_0 \simeq (n[\mathrm{cm}^{-3}])^{1/2}$ eV/cm, plasma waves. This process is analyzed using the nonlinear theory and scaling laws are derived for the various wakefield quantities. It is found that the axial field of the wake scales as $E/E_0 \simeq a^2/(1+a^2)^{1/2}$, where $a = |eA|/mc^2$ is the normalized laser field. These large amplitude wakefields may be used to i) accelerate a trailing electron bunch (laser wakefield acceleration[2]), ii) optically guide a trailing laser pulse, iii) upshift the frequency of a trailing laser pulse and iv) enhance the coherent harmonic radiation generated by a laser pulse.

At sufficiently high powers, $P \geq 17\omega^2/\omega_p^2$ GW, relativistic optical guiding may prevent pulse diffraction within the plasma. Using the self–consistent nonlinear theory, optical guiding is analyzed including the effects of the longitudinal motion and density response of the electrons in addition to the relativistic electron quiver motion. Relativistic optical guiding is found to be ineffective in preventing the leading portion ($\leq$ a plasma wavelength) of a laser pulse from diffracting. Hence, to prevent short pulses from diffracting, it may be necessary to relay on additional guiding mechanisms, such as by using a preformed density channel or a relativistic plasma wave. Preliminary results of 3D particle simulations of these processes will be presented.

*Work supported by DOE and ONR.

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

[2]P. Sprangle, E. Esarey, A. Ting and G. Joyce, Appl. Phys. Lett. 53, 2146 (1988).

COLLECTIVE PARAMETRIC INSTABILITIES OF MANY OVERLAPPING LASER BEAMS WITH FINITE BANDWIDTH*

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We consider a class of parametric instabilities resulting from the overlap of a symmetric array of laser beams with finite bandwidth focused at a common point in a plasma. When the N wavevectors $\underline{K}_{ob}$ (b=1, - -, N) of the laser beams are symmetrically distributed on a cone and $|\underline{K}_{ob}| = \underline{K}_o$ (for all b) we argue that 'collective' parametric instabilities can be excited in which a common daughter wave with wave vector, $\underline{K}_1$, parallel (or anti-parallel) to the cone axis is coupled to an array of daughter waves whose wavevectors, $\underline{K}_{2b}$, lie on another cone and are determined by the matching conditions, $\underline{K}_{ob} = \underline{K}_1 + \underline{K}_{2b}$ and $\omega^{(o)}_{\underline{K}_o} = \omega^{(1)}_{\underline{K}_1} + \omega^{(2)}_{\underline{K}_{2b}}$.

The analysis is based on the Random Phase Approximation equations which require that the individual beams have a finite bandwidth, Δk_o, around $\underline{K}_o$, and we also allow for a small range of wave vector directions about $\underline{K}_{ob}$ for each beam. For a sufficiently large number of beams the collective thresholds are lower and the growth rates are higher than those for the single beam instabilities which are peaked for both daughter wave vectors along the individual beam axes. The limiting cases of well separated beams and 'close packed' beams will be discussed. To be effective the spatial extent of the beam overlap region must be long enough to allow significant convective amplification or absolute instability. The study is motivated by the multi-beam Aurora laser geometry and has other applications as well.

*Supported by USDOE

FILAMENTATION INSTABILITY FOR MULTIPLE OVERLAPPING BEAMS WITH FINITE BANDWIDTH AND ISI

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It has been shown that for sufficiently large bandwidth, a simple model is obtained which describes the evolution of the plasma density in response to the average laser intensity[1.] This Broadband Induced Spatial Incoherence, or BISI model, is used to study the linear filamentation instability of an array of laser beamlets.

If the beamlets overlap such that the mean laser energy spectrum is smooth, i.e. a Lorentzian with transverse wavenumber width Δk, then the spatial convective gain rate is reduced, for a perturbation with wavenumber k, by an amount which varies as k$\cdot\Delta$k.

If the beamlet energy spectra are disjoint, then at threshold the marginally stable mode maybe oscillatory in z, unlike the overlapping case. Other results for this case will be presented.

[1]"Laser Filamentation: Transient Linear Response, Broadband ISI effects and supersonic collapse," H. A. Rose, D. F. DuBois and D. Russell, Los Alamos preprint in LA-UR-89-3349. (Submitted to Soviet Journal of Plasma Physics, 1990)

A KINETIC THEORY OF LASER BEAM THERMAL FILAMENTATION IN PLASMAS

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The classical linear theory of laser beam thermal filamentation has been extended to include the effects of nonlocal electron heat transport. The new theory reduces the threshold for filamentation and predicts an optimum perturbation wavelength that maximizes the exponential growth. Classically one would have expected constant growth over a wide range of wavelengths. Results are compared with recent experimental observations of laser beam filamentation by Youngs, et al., *Phys. Rev. Lett.*, 61, 2336 (1988).

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TRANSVERSE MODULATIONAL INSTABILITY OF COUNTERPROPAGATING WAVES AND CONICAL RADIATION

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Conical radiation has been observed for both single pump geometry in the self focusing regime and for counterpropagating pump geometry in the self focusing and self defocusing regimes when sodium gas is the nonlinear medium.[1,2] This scattered radiation is observed at small, discrete angles located symmetrically about the pump-beam axis. The radiation scattered at the smallest cone angle dominates and has the same frequency as the pump radiation. This phenomenon has been modeled as a nonlinear wave mixing process in which the pump radiation is coupled to transverse side-band modes. Predictions made with this model are in agreement with the experimental observations. In this paper, we will consider the extension of this model to plasmas in which ponderomotive self focusing dominates and either resonant or nonresonant ion motion exists.

1) J. Pender and L. Hesselink, *IEEE J. Quantum Electron*, QE-25, 395 (1989).
2) G. Grynberg, E. Le Bihan, P. Verkerk, P. Simoneau, J.R.R. Leite, D. Bloch, S. Le Boiteux, and M. Ducloy, *Opt. Commun.*, 67, 363-366 (1988).

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FILAMENTATION OF OBLIQUELY INCIDENT LASER LIGHT IN INHOMOGENEOUS PLASMAS

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The filamentation instability arises from the interaction of the pump laser light with a density perturbation aligned along the laser propagation direction and two sidebands at slight angles to this direction. The instability is well understood in homogeneous plasmas. However, if the laser light is obliquely incident on an inhomogeneous plasma the sidebands are affected differently by refraction as they propagate, which tends to reduce their coupling to the density perturbation and results in a reduction in the spatial growth rate for filamentation. This effect may be especially significant for direct-drive laser fusion, where most of the light is obliquely incident and where uniformity of illumination is a particular concern. Estimates of the magnitude and significance of the effect will be provided for plasma parameters relevant to direct drive targets.

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ARE SUPERSONICALLY COLLAPSING FILAMENTS STABLE?

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It has been shown that ion inertia allows for supersonically collapsing filaments when the trapped power greatly exceeds the critical power needed for filamentation in the adiabatic ion regime[1]. The stability of these filaments to nonaxisymmetric perturbations is unknown.

A two dimensional code with an equivalent three dimensional ponderomotive force (pmf $\sim |E|^4$) is being studied to address the stability question for an isolated filament and also to study the long time behavior of a multiple filament regime.

Two dimensional models with the regular pmf nonlinearity result in weaker filaments, which are qualitatively different in their properties.

[1]"Laser Filamentation: Transient Linear Response, Broadband ISI effects and supersonic collapse," H. A. Rose, D. F. DuBois and D. Russell, Los Alamos preprint LA-UR-89-3349. (Submitted to Soviet Journal of Plasma Physics, 1990)

Laser Fusion to Space and Environmental Research

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Laboratory experiments using laser and microwave excitation have demonstrated the generation of fast electrons and density perturbations at the resonant layer and enhanced scattering in the underdense region. This paper will discuss the application of these concepts to space plasmas under high power EM irradiation at HF frequencies. In addition the coupling between high frequency EM waves to low frequency ion cyclotron waves and Alfven waves which propagate globally will be shown. The use of anomalous resistivity in the modulation of an ionospheric current will be discussed using induced ion waves. The impact of globally excited waves on environmental issues will be addressed in terms of selective ion removal. Finally a new diagnostic of space plasma using the combined high power EM waves and laser fluorescence on nitrogen ions and neutrals will be discussed.

Research supported by LLNL, ONR and UCLA.

BANQUET

BUSINESS MEETING

R. Johnson, Chair

BANQUET TALK

N. Delameter, Chair

Hubble Space Telescope Project

John Clarke

Department of Atmospheric, Oceanic, and Space Sciences
University of Michigan

ORAL SESSION 4

R. Kauffman, Chair

X-ray Diagnostics and X-ray Lasers

Laser-matter interaction at intensities of 10^{12} W/cm^2 and below

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For single pulsed laser-matter interactions at sufficiently high intensity, the electron density in the ablated vapor is large enough to absorb the laser radiation before it can reach the dense target material. The resulting interaction can be described in terms of energy flows: laser energy is absorbed in the plasma in front of the target and reappears as thermal electron energy and secondary radiation, part of which impinges upon and heats the dense target material at the dense material-vapor interface. This heating in turn drives ablation, thereby providing a self-consistent mass source for the laser absorption, energy conversion, and transmission. Under typical conditions of laser intensity, pulse width and spot size, the flow patterns can be strongly two-dimensional. We have modified the inertial confinement fusion code LASNEX to simulate gaseous and some dense material aspects for the relatively low intensity, long pulse-length conditions of interest in many laser-related applications. The unique aspect of our treatment consists of an ablation model which defines a dense material-vapor interface and then calculates the mass flow across this interface. The model, at present, treats the dense material as a rigid, two-dimensional simulational mass and heat reservoir, suppressing all hydrodynamical motion in the dense material. The modeling is being developed and refined through simulation of experiments, as well as through the investigation of internal inconsistencies, and some simulation of model problems. The computer simulations and additional post-processors provide a wealth of predictions for possible measurements, including impulse given to the target, pressures at the target interface, electron temperatures and densities, and ion densities in the vapor-plasma plume region, transmission and emission of radiation along chords through the plume, total mass ablation from the target and burn-through of the target material at selected radial locations. We will present an analysis of some relatively well-diagnosed experimental behavior which has been useful in development of our modeling.

DEMONSTRATION OF FREQUENCY UPSHIFTING OF ELECTROMAGNETIC RADIATION BY A RELATIVISTIC IONIZATION FRONT

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A novel technique for upshifting the frequency of electromagnetic radiation via its interaction with a relativistically propagating laser-produced ionization front has been both theoretically and experimentally investigated. Theory predicts that although the plasma created by laser ionization of the neutral gas is, in the ionization front's rest frame, below the critical density for the initial e.m. radiation ($2\gamma\omega_i \gg \omega_p$), large frequency upshifts ($\omega_{final}/\omega_{initial} \approx 1 + \frac{\omega_p^2}{4\omega_i^2} \gg 1$) can be obtained. We have experimentally observed frequency upshifts of greater than a factor of four ($\omega_{final}/\omega_{initial}$) when counterpropagating microwave radiation at 33.5 GHz interacts inside a resonant microwave cavity with an ionization front created by an intense, 50 picosecond long ultraviolet (266 nm) laser pulse. The frequency of the upshifted radiation can be continuously tuned from 33.5 GHz to greater than 116 GHz by varying the neutral gas pressure inside the microwave cavity, hence the front's plasma density. This technique may provide a new class of tunable radiation sources operating at frequencies from the microwave regime through the ultraviolet.

This work is supported by D.O.E.

FINE-STRUCTURE SATELLITES AND THE TEMPERATURE DEPENDENCE OF X-RAY ABSORPTION LINES IN HIGH-TEMPERATURE PLASMAS

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Absorption spectroscopy has been used to infer the areal density of compressed layers in spherical targets imploded by means of high-intensity laser irradiation. The absorption signal is due to the 1s-to-2p transitions in the helium-like through fluorine-like species of ions in the shell. Earlier work assumes that all absorption begins from the ground state of each species. Each species forms a distinct line-like absorption band, so the areal density of each species can be inferred from the attenuation in the spectrum and from the known cross-sections for each 1s-to-2p transition from ground. This work shows that absorption transitions from excited states of the ions contribute to the total line opacity of each species and that, as a result, the opacity becomes temperature dependent through the temperature dependence of the populations of excited states. This is shown both for a simple screened hydrogenic model and for the specific case of chlorine. The excited states are less opaque than the ground states. As a result, estimates of areal density based on assuming pure ground states can be too low by as much as about 30%.

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Detailed Configuration Accounting Opacities Computed with Statistical Term Structure*

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Radia 've opacities, computed in configuration to configuration detail, are sometimes sensitive to the treatment of term structure in the transition array. Brute force atomic structure calculations can be prohibitively time consuming (due to the many configurations th ,t must be considered) and unresolved transition array methods oft lead to inaccurate values for the Rosseland Mean. As an altern tive, we have developed a statistically motivated method in which individual level to level transitions are included explicitly. Cal ulated opacities comparing DCA, UTA, and detailed level to level sults will be presented.

*Work performed under the auspices f the U.S. Dept. of Energy by the Lawrence Livermore National Laboratory under contract 7405-Eng-48.

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NE-LIKE X-RAY LASERS FROM THICK TARGETS

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X-ray lasers have been produced using both exploding-foil targets and thick slabs. The latter geometry is expected to be dominated by refraction and incapable of supporting significant propagation lengths. In these experiments thick targets were irradiated with 600-800 ps pulses of 1054 nm light focused to intensities of ~10^{13} W/cm^2. Lasing was observed from both germanium and titanium targets. The angular intensity distribution of the output of these lasers is presented and analyzed.

We perform 3-D ray tracing calculations through the density profiles obtained from a two-dimensional hydrodynamic code to simulate the propagation of x rays in the target. To simulate the gain profiles we use an atomic physics code to determine the gain as a function of temperature and density. Correctly replicating the output characteristics of the laser helps us understand the dynamics of slab targets. We show the merits of a curved target which has been proposed to overcome refraction effects.

Finally, we comment on the nature and behavior of the titanium laser.

"This work was supported by the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics, and partially supported by the Naval Research Laboratory under Contract N00014-86-C-2281, and by a subcontract from the University of Texas at Dallas, and the University of Rochester."

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Dynamics of Neonlike Lasers in Exploding-Foil Plasmas*

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We report on recent neonlike XUV laser experiments at the NOVA 2-Beam Facility at Livermore. Our targets were primarily thin foils (< 2000 Å) of germanium or silver on 1000 Å plastic backing irradiated by 0.53 μm light. We used germanium (Z=32) as the focus of an overionization study. We had expected to strip the germanium ions well past the neonlike ionization stage and effectively terminate the lasing. Instead, for the highest intensity shots the neonlike lasing became weaker and shifted in time to the recombination phase of the plasma. This late time behavior is observed for NOVA laser intensities near 4×10^{14} Watts/cm^2. A new timing fiducial on the streaked spectrographs gives an absolute determination of both the time history of the XUV lasing spectra and the spontaneous x-ray spectra relative to the incident 500-ps Gaussian NOVA laser pulse. We hope by correlating these spectra to understand the change in dynamics of the neonlike lasing with the charge state history. We also achieved particularly strong lasing in neonlike silver (Z=47) at 99 Å. The gain coefficient appears to be as high or higher than for any other neonlike ion to date. Along with our more conventional 500-ps experiments, we are exploring short pulse (20-ps) laser irradiation of targets as additional neonlike recombination experiments.

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

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8.5
1.75

High Resolution X-ray Laser Linewidth Measurements*

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and

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Abstract

We have performed high resolution time-resolved x-ray laser lineshape measurements on the Ne-like Se x-ray laser operating at 20.638 nm. Using a 6m varied line space grating spectrometer[1] we have obtained x-ray laser spectra with a resolving power as high as 26,000. We will show examples of this data which illustrates gaussian lineshapes having widths significantly smaller than that associated with the expected Doppler broadening. We attribute these lineshapes to gain-narrowing produced by GL>10 amplifiers. We will also discuss measurements that we plan to perform with this apparatus, which include intrinsic lineshapes in x-ray amplifiers and examples of saturated laser line profiles which may illustrate some interesting effects of high gain.

1) M. Hettrick et al, Appl. Opt. 27, 200 (1988)

• 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.

Temperature Determination of High-Z Laser Produced Plasmas Using K-Shell Spectroscopy*.

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We report on recent laser-produced plasma experiments designed to test the temperature dependence of L-shell emission in high-Z plasmas using K-shell spectra The experiments were performed at KMS Fusion using the Chroma laser system configured to produce 0.53 µm , 0.5 to 1.3 ns laser light focussed to over-fill 50 and 100 µm diameter dot targets The dot target design served to minimize radial gradients and produce a 1-d expansion off the substrate surface. The targets consisted of either a high-Z/low-Z mixture pressed into a 50 µm diameter hole drilled into a plastic substrate or 50 µm diameter high-Z material coated onto a 100 µm diameter low-Z material supported by a plastic substrate. The plasmas were diagnosed using three spatially and temporally resolved spectrometers, a temporally resolved pinhole camera viewing radial emission, a high magnification (19X) pinhole camera viewing axial emission, four-frame holographic interferometry, and various laser diagnostics. Data will be presented along with current analysis.

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

DISCUSSION SESSION

R. Berger, Chair

MIXED POSTER SESSION 4

A Numerical Study of X-Ray Emission from the Central Plasma in a Low Pressure Spherical Pinch.

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A part-analytical, part-numerical model has been developed and used to calculate transport properties to predict bremstrahlung emission of soft X-rays in the central plasma of a low pressure Spherical Pinch machine. The algorithm includes the effect of the self-consistent electric field (albeit in a one-dimensional approximation) and relies on a Fokker-Planck treatment of interactions among electrons and between electrons and ions.

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Influence of $1s2l3l'$-$1s^{2}2l$ Satellite Lines on Density Determinations from Stark Broadening Analysis

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Density determination from analysis of Stark broadened spectral lines has long been reliably used to diagnose high density plasmas, but its accuracy can be affected both by opacity and nearby neighboring lines which may be blended. A reanalysis of previous NOVA data is presented in which the effects of $1s2l3l'$-$1s^{2}2l$ satellite lines of the Ar He_{β} line on the inferred densities from Stark broadening are studied. The data is analyzed with a curve fitting code to deconvolve the observed satellite line components. The lack of proper accounting of blended satellite line components could lead to an overestimate of electron density since the satellite lines increase the apparent FWHM of the He_{β} line profile. A model is presented based on detailed atomic data calculations[1] which is used to calculate satellite components in the LTE and coronal limits. This model is used to estimate uncertainties in densities inferred from He_{β} profile fits. The model can then be included in a detailed spectroscopy generator such as RATION[2] so that the full kinetics calculation will include these satellite lines in the final output spectrum.

[1] D.H. Sampson, et.al., Atomic Data and Nuc. Data Tables, **32**, 343 (1985).
[2] R.W. Lee, et.al., JQSRT, **32**, 91 (1984).

Development of a Collective Thomson Scattering Diagnostic Using the Ion Acoustic Decay Instability.*

by

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+Laboratory for Laser Energetics, University of Rochester.

We have extensively studied[1,2] the Ion Acoustic Parametric Decay Instability (IADI) in laser produced plasmas. Our results on the IADI not only raise important issues for ICF target designs, but they also show that the properties of the plasma near the critical density surface can be effectively diagnosed using the IADI.

We are presently developing a collective Thomson scattering diagnostic which uses the ion acoustic waves generated by the IADI to determine electron temperature, ionic charge state, and plasma density (near critical). A further extension of these measurements also permits studying the linear and nonlinear evolution of the ion acoustic waves by measuring their k-spectra and their angular distribution.

The experiments are planed to be carried out on the GDL laser system at the National Laser Users Facility at the University of Rochester's Laboratory for Laser Energetics. In these experiments a 200 J, 1 μm laser with a 1 nsec pulse duration is normally incident on planar CH targets. The IADI threshold for large spot sizes lies near $5x10^{12}W/cm^2$. A short pulse probe (λ=267nm, $t_p \approx 10$ to 20 psec) will be used for collective Thomson scattering from the ion acoustic waves.

The experimental program is carried out at the National Users Facility at LLE, University of Rochester, with support from the USDEO under Cooperative Agreement. The work performed at LLNL is partially supported by the Plasma Physics Research Institute, University of California, and LLNL.

[1]K. Mizuno, W. Seka, R. Bahr, R.P. Drake, P.E. Young, J.S. DeGroot, and K.G. Estabrook, in *Laser Interaction and Related Phenomena*, vol. 9, ed. by H. Hora and G.H. Miley (in press).

[2]K. Mizuno, P.E. Young, W. Seka, R. Bahr, J.S. DeGroot,R.P. Drake, and K.G. Estabrook, "Investigation of Ion Acoustic Decay Instability Thresholds in Laser Plasma Interactions", UCD Report PRG-M-185 (1990).

Subharmonic Generation in Large Amplitude Relativistic Plasma Waves Excited by Collinear Optical Mixing

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The non-linear dynamics associated with the generation of a relativistic electron plasma wave through collinear optical mixing in a spatio-temporally modulated plasma is studied through analytic and numerical modeling. The system has been analyzed analytically in a Lagrangian frame so as to rigourously treat the non-linear contribution of the relativistic mass increase of the fluid elements, in intense laser fields. The obtained model equation has been solved numerically since resorting to a slowly varying wave approximation precludes one from observing subharmonics. In a uniform plasma only bistability and hysteresis have been observed when different system parameters, such as plasma density or laser intensity, are varied in time. In the presence of a short wavelength density modulation however, a parameter regime has been found for which, in addition to the aforementioned bistable behavior, incomplete Feigenbaum cascades and a complete period doubling route to chaos has been observed.

Self-consistent simulations using a fully relativistic PIC-code, which include competing effects not included in the simplified analytic model, have shown the generation of subharmonic frequencies of the driver frequency in the electromagnetic wave spectrum. This supports our main conclusion that under appropriate conditions such a plasma wave can indeed undergo bifurcations leading to half-harmonics in both space and time domain.

This work is supported by D.O.E.

ACCELERATION OF FLYER PLATES BY CONTAINED LASER PLASMAS -- RECENT EXPERIMENTS AND SIMULATIONS

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Short-duration (10 ns) low-fluence (10 J cm^{-2}) laser pulses incident directly upon the bonded interface between a thin (1-5 micron) aluminum film and its supporting fused quartz substrate have been used in recent laboratory experiments to accelerate such films up to velocities of order 6×10^5 cm s^{-1}. The accelerated foils remain intact and exhibit a high degree of planarity, thus comprising miniature "flyer plates" that can be used for a variety of purposes.

The foil acceleration occurs by virtue of the high pressure of the laser-produced aluminum plasma immediately adjacent to the interface during the laser pulse. This "contained" plasma is almost perfectly tamped by the solid transparent (at the laser wavelength) substrate material through which the incident laser beam freely passes. Thus, most of the absorbed laser energy is available for the foil acceleration, which may occur over times of several laser pulselengths. Edge-on "snapshots" of the accelerated foils taken in visible light a few tens of nanoseconds after the laser pulse illustrate the overall high level of foil integrity routinely achieved in these experiments, while at the same time they provide direct experimental evidence for Rayleigh-Taylor instabilities at the foil's trailing edge.

In view of these results, LASNEX 1-D simulations of the laser absorption/flyer-plate acceleration process have been carried out to gain further insight into this example of contained vaporization. The numerical hydro simulations include treatment of the laser absorption and plasma ignition processes, as well as conductive and radiative losses into the quartz substrate. Moreover, an elastic-plastic strength model allows the motion of that part of the aluminum remaining intact throughout the acceleration phase to be followed. The calculated final velocities reached are in good agreement with the measured values on specific shots, and these confirm that the conversion efficiency of laser radiation into kinetic energy can be quite high (> 60 percent). Techniques for raising the kinetic conversion efficiency even higher are currently being investigated via additional laboratory experiments and calculational efforts, and these will be described in some detail. In addition, the calculations indicate that only a tiny fraction of the foil need be vaporized in order to provide the necessary driving pressures, a result which is not inconsistent with measurements of the mass of recovered foil samples on several shots. Finally, the predicted plasma temperatures are in the range 10-12 eV; thus the thermal emission should peak at soft X-ray wavelengths and be readily observable in a side view of the separating foil-substrate configuration. The direct detection of such emission in experiments planned for the near term will provide a strong constraint on future laser-target modeling of accelerated metal foils.

*Research performed under the auspices of the U. S. Department of Energy.

TWO-DIMENSIONAL MODELLING OF REFRACTION EFFECTS IN A PLASMA FIBER WAVEGUIDE

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ABSTRACT

The problem of laser beam refraction due to multi-photon ionization in a long scalelength plasma filament is discussed. For a uniform density gas target it is shown that refraction can limit the intensity of the focussed laser beam to a value near to the threshold for multi-photon ionization. In order to create large volumes of underdense plasma, it is shown that it is necessary to have a preformed density minimum in the non-ionized gas target. Parameters will be determined for such a structure to act as an indestructible waveguide for intense sub-picosecond laser pulses.

NON MAXWELLIAN DIELECTRONIC SATELLITE SPECTRA IN PICOSECOND LASER INTERACTION ON ALUMINUM

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Spectra of dielectronic satellite lines of aluminum He-like $1s^2$-1s2p obtained during the interaction of picosecond laser pulses with an aluminum target have been recently obtained with the picosecond Nd:Yag laser of the Ultrafast Science Laboratory at the University of Michigan. The spectra show a strikingly anormal ratio of the k-j to a-d satellite features (in Gabriel's notation) indicating that the population processes (respectively electron capture and inner-shell collisional excitation) could be non-thermal. To investigate this point, a time-dependent collisional-radiative model describing the populations of all the doubly excited levels of aluminum Li-like ions and a large set of singly excited Li-like and He-like ions have been used to interpret the experimental data. In this model, non-maxwellian effects have been incorporated by assuming that the electronic energy distribution function can be approximated by a two temperature Maxwellian distribution.

In the experiments, laser energy was about 70 mJ in a 1ps pulse superimposed on a several ns pedestal containing less than 0.1% of the total laser energy. Spectra were accumulated over ≈20 shots with a Van Hamos spectrograph consisting of a 10 cm curvature radius PET crystal. The spectrograph worked around 1.6 keV and the data was recorded on SB392 film filtered with 0.8 μm Al to avoid visible light exposure.

To simulate the interaction of this high laser intensity with the aluminum target, we have also used a one-dimensional code with time-dependent atomic physics where the absorption was calculated by solving the linear electromagnetic field equation with collisions.

Comparison of experiments with hydrodynamic and atomic simulations show that non-thermal effects are mainly responsible of the anomalous dielectronic satellite line ratio. The energy distribution can be approximated by the superposition of 200-300 eV and 1 keV Maxwellian distributions.

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THE INTERACTION OF PICOSECOND LASER PULSES WITH SOLID TARGETS

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We have studied the interaction of short (less than 10 picoseconds) laser pulses with solid targets. In particular the laser absorption was measured for s and p polarised light, whilst the density and temperature of the plasma were determined from X−Ray spectroscopic measurements. In addition the ionisation balance of high and medium Z ions was studied, the X−Ray spectra being identified with the aid of a multi−configurational Dirac−Fock code. The general plasma conditions were simulated with a 1D hydrodynamic code.

XUV Gain Measurements in a Collisionally Excited Germanium Plasma

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We have observed gain on five 3p-3s transitions of neon-like germanium. The Ge XXIII plasma was produced by irradiating solid Ge targets with a 60 μm x 10 mm line focus of the LP2 Nd:glass laser system. For most of the experiments a 1.5 ns (200 ps risetime) pulse with ~100 J incident energy was used. Two flat-field XUV spectrographs recorded the emission along the line focus axis and in the transverse direction. The 3p-3s emission occurred in a narrow 10 mr wide beam pointing slightly forward from the target surface. Gains up to ~4 cm^{-1} have been inferred for the 19.6 nm (J=0-1) and 23.2 nm (J=2-1) lines. A strong dependence of the inferred gain on the incident pulse shape has been observed.

Recent Progress in the Development of Nickel-like X-ray Amplifiers Near the Carbon K Edge*

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Abstract

Ni-like x-ray lasers have been produced at wavelengths near to, and below that of the K absorption edge of carbon (43.76 Å). Recent work has concentrated on the development of the Ni-like Ta amplifier at 44.83-Å. Amplification occurs in a laser produced plasma created by irradiating a thin foil of Ta with two beams of the Nova laser. Up to 8 gain lengths has been demonstrated, so far, with a gain coefficient of 2.5 cm^{-1} and a gain duration of 250 psec. The wavelength of 44.83-Å is close to optimal for holographic imaging of live cells. It remains to optimize the coherent output power of the amplifier, in order to use it as a source for future x-ray holography experiments. Extrapolation to shorter wavelengths has resulted in Ni-like tungsten producing a gain of 2.6 cm^{-1} with a total of 7 gainlengths of amplification, at 43.18-Å. This wavelength is on the short wavelength side of the carbon K edge and so is the first demonstration of an x-ray amplifier within the "water window". Further experiments with Ni-like gold have extended the spectroscopy of these laser transitions to 35.6-Å and ongoing experiments are attempting to measure the gain at this wavelength. Also of interest is the observation of analogous Co-like lasing lines in both Yb and Ta x-ray laser plasmas. These lines appear with a small amount of gain, when the plasma is overionized. Their presence has significance as one issue in the study of Ne-like x-ray lasers is that, to date, there has not been an observation of expected F-like analogues.

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Electron energy distribution functions in neon-like X-ray lasers

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We have used our electron kinetic code FPI[1], augmented with a coronal atomic physics package, to study the electron distribution function under the combined effects of (1) inverse Bremsstrahlung heating, (2) electron-electron collisions and (3) inelastic collisions (collisional excitation and ionization, radiative and die-lectronic recombination). We find that for physical conditions relevant to the Ne-like exploding Molybdenum foil X-ray laser[2], the form of the distribution function is quite similar to what was found previously[1], in the absence of inelastic processes:

$$f_0(v) \sim \exp(-v^m/v_0^m), \text{ with } m = 2 + 3/(1 + 1.66/\alpha^{0.724}) \qquad (2 < m < 5)$$

$$\text{where } \alpha = Z\frac{V^2_{osc}}{V^2_{th}} = Z\frac{I}{10^{14}\,\mathrm{Wcm^{-2}}}\,\frac{\lambda^2}{(1.06\ \mu\mathrm{m})^2}\,\frac{0.042\ \mathrm{keV}}{kTe}$$

This is because, in this situation, the ionisation state is close to the equilibrium value, and radiated energy is only about 15% of that absorbed.

On the other hand, if the ionisation state is far below the equilibrium value (as might occur, for example, if a foil were exploded with a long, low intensity pulse and then suddenly heated with an shorter, higher intensity one) then, as much as 50% of the absorbed energy is radiated, and the electron distribution function is more maxwellian than might be expected on the basis of the above formula: the shape is still $\exp(-v^m/v_0^m)$, but with m closer to 2. This effect will be further explained and quantified.

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b) P. Alaterre, J.P. Matte and M. Lamoureux, Phys. Rev. A34, 1578 (1986)

2 B.J. MacGowan et al., J. Appl. Phys. 61, 5243 (1987)

Short Pulse Collisionally Pumped Soft X-ray Laser

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Predictions for Collisionally Pumped Cobalt-like X-Ray Lasers*

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We present predictions for cobalt-like lasing transitions obtained from a detailed collisional radiative model which includes all $\Delta n=0$ collisional transitions and important radiative cascades. These calculations are motivated by recent observations of soft x-ray lasing of 4d-4p transitions in cobalt-like ions.[1] These transitions are the cobalt-like analogs of the J=0-1 lasing transitions produced by monopole excitations in nickel-like ions. Similar fluorine-like analogs to neon-like J=0-1 transitions are predicted to have significant gain,[2] but have not been observed.

1 B. J. MacGowan, 7th APS Topical Conference on Atomic Processes in Plasmas, Gaithersburg, 1989.
2 Peter L. Hagelstein, Phys. Rev. A **34**, 924, (1986).

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Measurement of Line-Coincidences in Resonantly Photopumped Short Wavelength Lasing Schemes*

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We report on recent x-ray spectroscopy experiments to measure proposed line-coincidences in resonantly photopumped short wavelength lasing schemes. One of these schemes is H-like Aluminum (Lyα) $[2p_{3/2} - 1s_{1/2}]$ photopumping the $[3d^{10} - 3d^{9}{}_{3/2}4f_{5/2}\ (J=1)]$ transition Ni-like Erbium (Er^{40+}).[1] We also examined Al-Lyα as a photopump for the $[1s^2 2s_{1/2} - 1s^2 5p_{1/2}]$ and $[1s^2 2s_{1/2} - 1s^2 5p_{3/2}]$ transitions in Li-like Iron (Fe^{25+}).[2] Simultaneously space- and time-resolved data were measured using an array of new Framing Intensified X-ray Spectrometers (FIXS) and X-ray Pinhole Cameras (FIX-PHC). These experiments were conducted at the CHROMA Laser Facility at KMS-Fusion. Our experiments demonstrate a novel method for measuring the prospective line-coincidence, measuring the absolute photoresonant pump strength, optimizing the conditions (T_e, n_e, and charge state distribution) for both the pump and the lasant plasmas, and studying the kinetics of the excited states of the lasant plasmas.

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Time resolved X-ray monochromatic imaging of Al and Ge line focus plasmas

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The uniformity of line focus plasmas is an important issue for the production of large gains and gain length products. We have completed an extensive set of experiments to address the problem of the uniformity of the plasma parameters along a line focus. A 10 mm by 60 μm line focus of the LP2 Nd:glass laser system, using a 1.5 ns pulse with a 200 ps rise time and 100 J of energy, produced Al and Ge plasmas with gain on various transitions[1]. Time resolved X-ray monochromatic imaging (keV range) and high resolution ($\lambda/\Delta\lambda \simeq 5000$) spectroscopy are used to study the ionization dynamics, the plasma homogeneity during and after the laser pulse. These diagnostics[2] allow the determination of the plasma parameters along the amplification axis. The quantitative study of large scale nonuniformities is realized by looking to the regions of an Al plasma where the He-like emission takes place. Ways to improve irradiation uniformity will by discussed.

1 G.D. Enright et al., this conference.

2 J.C. Kieffer et al., Appl. Opt. 28, 4333, 1989.

ANGULAR DISTRIBUTION OF RAMAN FORWARD SCATTERING*

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We consider Raman forward scattering in a hot, low density plasma. Direct forward scattering is rather insensitive to bandwidth but is quite sensitive to plasma inhomogeneity. Maximum growth is actually expected for forward scattering at an angle,[1] since the plasma wave then has a larger wavenumber. The onset of Landau damping provides an estimate for the optimum angle, although geometrical effects and bandwidth can also matter. The plasma waves associated with this forward scattering have phase velocities ranging from about the velocity of light down to the electron velocities and so can provide a ladder for electron acceleration to very high energy. Simulations and theory are presented to illustrate the angular dependence of the forward scattering and the novel character of the heated electrons.

1. J. J. Thomson, *Phys. Fluids* **21**, 2082 (1978).

* 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.

RESONANT FOUR-WAVE MIXING IN AN UNMAGNETIZED PLASMA*

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A low-density filament-discharge plasma is created in a large cylindrical chamber (75 cm diameter, 200 cm length) with multidipole magnetic confinement. Low temperature Hydrogen, Helium or Argon plasmas ($T_e \approx$ 2-4 eV, $T_i/T_e \approx 0.1$) are formed with a maximum electron density of 10^{11} cm^{-3}. High power microwaves (f_o = 3.24 GHz, duration $\approx$ 60 μsec) are passed through large-aperture horns centered along the chamber axis to produce two anti-parallel pump beams, with a maximum power of 30 kW per pump beam. A third horn (signal horn), tilted at a 50° with respect to the pump beams, launches the signal beam (with a maximum power of 1.2 kW, duration $\approx$ 60 μsec) and collects the phase conjugate reflected (PCR) power generated by resonant four-wave mixing (FWM) in the plasma.

Detailed experimental results are presented of resonant FWM in an unmagnetized plasma for a variety of plasma and beam conditions. Through the use of heterodyne frequency mixing techniques, direct time-resolved measurements of PCR power is achieved. A 38 GHz scattering system allows us to probe the ion waves generated by optical mixing in a nonperturbing manner. By controlling the frequency difference between the pump and signal beams, we are able to sweep through the ion-acoustic resonances of the plasma and compare the resonances seen by the PCR power measurements with that of the scattering system. Wide PCR resonances have been observed, which are thought to be primarily due to the large range of angles existing in the signal beam as it traverses the plasma. Also under investigation are the effects that beam-spreading and beam curvature have on the FWM process, and what limitations these factors impose upon possible applications of long wavelength FWM.

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STIMULATED RAMAN FORWARD SCATTERING AND THE RELATIVISTIC MODULATIONAL INSTABILITY OF LIGHT WAVES IN RAREFIED PLASMA

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Previous analyses of the stimulated Raman forward scattering (SRFS) and relativistic modulational instability (RMI) of light waves have treated these instabilities separately. In a rarefied plasma, however, they are closely-linked branches of the *same* instability. The results of a unified analysis of the SRFS and RMI of light waves in homogeneous plasma will be described and their consequences for beat-wave particle acceleration and current long-scale-length fusion experiments will be discussed briefly.

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TIME/SPACE-RESOLVED SPECTROSCOPY OF 2ω AND 3ω/2 FROM LASER IRRADIATED THIN FOIL PLASMAS

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A systematic study of harmonics of laser light generated in an underdense plasma is in progress at IFAM as a contribution to the laser fusion diagnostic methods. The plasma is produced by irradiating thin foil plastic targets with 1.064μm laser light in a 3ns laser pulse. Electron density drops to the critical value before the peak of the pulse; temperature is hundreds of eV. Time resolved measurements are performed with an optical streak camera; spectra are obtained with a 1m spectrometer. The spiking character of the emission allows also to use a special spectrometer-streak configuration to obtain time resolved spectra with spatial resolution.

Second harmonic generation has been observed forward, backward and perpendicularly to the laser beam. 2ω emitted perpendicularly has been analysed both spatially and spectrally, giving evidence for sum frequency of incident laser light and light backscattered by stimulated ion acoustic waves [1]. These spectra can provide a temperature diagnostics with spatial resolution along the beam path. A correct use of 2ω side-emission as a diagnostics for filamentation is under discussion [2].

Three half harmonic has been studied perpendicularly to the laser beam. Time resolved spectra seem to be consistent with a model accounting for two-plasmon-decay (TPD) of laser light, plasmon propagation and coupling with laser photons in the $n_c/4$ regions ahead and behind the density peak. The nominal laser irradiance at which we observed the onset of 3ω/2 generation is much lower than the theoretical value for TPD.

[1] A.Giulietti et al., Phys. Rev. Lett. **63**, 524 (1989)

[2] P.E.Young et al., Phys. Rev. Lett. **63**, 2812 (1989)

CALCULATIONS OF LANGMUIR WAVE K-SPECTRA NEAR QUARTER-CRITICAL DENSITY

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Both the stimulated Raman scattering (SRS) and the two-plasmon decay (TPD) instabilities contribute to the Langmuir wave spectrum near quarter-critical density. Langmuir waves generated by the absolute SRS instability have wavenumbers $k_x \cong -k_o$ and $k_y \cong 0$, where $\mathbf{k_o}=k_o$ and $\mathbf{E_o}=E_o\mathbf{y}$ are the wavevector and the electric field vector of the laser respectively. The absolute TPD instability generates a range of Langmuir wave wavenumbers satisfying $k_{min}<k_y<k_{max}$, where k_{min} is in excess of k_o for low temperature plasmas. Hence one expects a gap in the Langmuir wave k-spectrum near quarter-critical density for $0<k_y<k_{min}$. Recent measurements in low-temperature plasmas[1], however, found a continuous Langmuir wave spectrum near quarter-critical density for $0 \leq k_y \leq 5k_o$.

We use the SATIN code[2] to calculate the Langmuir wave k-spectrum near quarter-critical density for a variety of plasma parameters. The code solves the coupled mode equations for SRS and TPD in a density gradient including pump depletion and second order nonlinear mode coupling. The code solves directly for the two-dimensional electric field amplitude of each frequency mode rather than separating longitudinal and transverse components. Thus the approach is valid for the entire spectral range of interest, including small values of k for which the SRS and TPD instabilities merge. The calculations will be compared to the experimental results reported in reference 1.

1 J. Meyer and Y. Zhu, to be published in *Phys. Rev. Lett.* 64, 2651 (1990).
2 L.V. Powers and R.L. Berger, *Bull. Am. Phys. Soc.* 30, 1527 (1985).

SIMULATION OF A LASER-IMPLODED GOLD-COATED GLASS MICROBALLOON WITH A RADIATION DEPENDANT IONIZATION MODEL.

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Implosion of gold-coated glass microballon[1] was performed in 1987 on the two beams 20kJ Phebus facility. X-ray pinhole images, both time integrated and streaked has been recorded. We present here 2D numerical simulation of this experiment including 3D X-ray tracing simulation of the above diagnostics. A good agreement with the experience can be obtained only through the use of a non-LTE ionization model **including** effects of the X-ray reabsorption. It implies ionization enhancement, increased internal energy, thus the hydrodynamics and specially the calculated expansion velocities are modified. The constructed streaked photographs are compared with the experimental records.

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[1] proceedings of the 12th AIEA conference, NICE Oct. 1988
G. Thiell et al., Laser and Particles Beams 6,93 (1988)

ORAL SESSION 5

W. Mori, Chair

Laser-Plasma Interactions II

MULTI FRAME INTERFEROMETRIC STUDY OF A LASER IRRADIATED PLASMA IN THE PRESENCE OF THE TWO PLASMON DECAY INSTABILITY

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The temporal development of the electron density distribution in a CO_2-laser produced plasma is studied interferometrically at 10.5 GHz framing rates with 50ps resolution. The plasma is produced in a helium gas jet target and has a maximum density of 5×10^{18} cm^{-3}. Thomson scattering of probe ruby laser radiation shows that the two plasmon decay instability is excited in this plasma. Excellent correlation between the density scalelength just below quarter critical density and two plasmon decay wave intensity demonstrates the instability quenching property of ponderomotive profile steepening.

Production of three-halves harmonic emission in laser-produced plasmas*

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Abstract

Recent experiments which explored the production of emission near three-halves harmonic of the incident laser frequency, ω_o, will be discussed. The spectrum near $3\omega_o/2$ usually consists of two peaks, one blue-shifted and the other red-shifted with respect to $3\omega_o/2$. The blue-shifted (red-shifted) peak is usually associated with two-plasmon decay plasma waves which are propagating up (down) the density gradient. Two-color experiments using the Nova laser[1] have shown that both peaks originate near $n_c/4$, which significantly constrains the production mechanisms for $3\omega_o/2$ emission. Experiments in which a single 1.06 μm beam irradiates a solid target have examined the dependence of the intensity of the blue-shifted peak on the level of SBS.

*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.

[1] P. E. Young *et al.*, Phys. Fluids B (June 1990).

PULSATION OF $3/2\omega_0$ AND X-RAY EMISSION FROM ND LASER PRODUCED PLASMAS

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We have recorded random spectral modulations in time integrated $3/2\omega_0$ spectra emitted from plasmas created by ≈100psec duration Nd laser pulses at intensities above 10^{15} W/cm^2 incident on solid targets. Time resolved studies show that the emission is modulated in time on a sub-10psec time scale. In accordance with our previous studies of fundamental and second harmonic emission, these observations imply the operation of a process which rapidly sweeps the frequency of the emission during each temporal burst. In the case of the two-plasmon decay instability, the most likely mechanism which can lead to frequency sweeping is rapid modulation of the electron temperature in the quarter critical region by bursts of fast electrons. We have searched for such bursts by time resolving K_α emission from an iron fluor in layered targets. The results of these experiments will be discussed.

FOUR-WAVE MIXING AND TIME-DEPENDENT PHASE CONJUGATION IN PLASMAS*

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We treat time-dependent four-wave mixing and phase-congugation in plasmas, taking into account resonant longitudinal plasma modes and effects of spatial nonuniformity. A space-time formulation of such 4-wave processes, based on the slowly-varying envelope approximation in the ponderomotive force regime yields linearized eqns, which are solved analytically as a combined initial/boundary-value problem in slab and inhomogeneous geometries. The plasma response is incorporated in a "grating" Green's function, expressed in terms of the linear quasilongitudinal susceptibilities. Grating response and decay times, and competing absolute modulational instabilities are found for degenerate and resonant 4-wave processes. We show that plasma nonuniformity can speed up the response of the conjugate wave and significantly alter the resonant absolute instability thresholds.

* 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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ABSORPTION OF POWERFUL ELECTROMAGNETIC RADIATION BY PLASMAS

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Absorption of powerful electromagnetic radiation with a frequency which is close to the plasma frequency and subsequent acceleration of electrons is an extremely complicated process for theoretical analysis. Numerical simulation of this process is also highly difficult. First, the properties of plasma turbulence excited by radiation are described only by means of three-dimensional models. Second, the electron acceleration is a kinetic process and demands particle simulation. However, there are limits for which a one-dimensional model could be sufficient.

Consider turbulence excited by radiation with rather large mismatch $(\omega_0-\omega_p)/\omega_0$. In this case, as a result of parametric instability the oscillations are excited with rather large values of wave numbers which are close to the strong Landau damping region. In this case, even under small broadening of the spectrum at the initial stage of modulation instability, the damping is sufficient to stabilize the instability. It is natural to assume that in the initial stage of the modulation instability, one-dimensional and many dimensional cases are close to each other and one-dimensional model is justified.

In the report, the results of one-dimensional particle simulation of radiation interaction with plasma are presented. The electron distribution function evolution and energy absorption rate were obtained. A one-dimensional particle simulation code which includes collisions was developed. The regimes when collisions suppress fast "tails" and when anomalous absorption leads to plasma heating are examined. Also two-dimensional particle simulations corroborating the adequacy of one-dimensional model were carried out.

CAVITON BURNOUT, THE BUMP-ON-TAIL ELECTRON VELOCITY DISTRIBUTION, AND FAST ION BEAMS

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Recent 3-D simulations of caviton collapse and burnout[1] contain much interesting information. In particular, there is some indication that electron burnout produces a local bump-on-tail velocity pulse downstream from the caviton structure. We will discuss the published results and some associated modeling.

Experiments at the Institute for General Physics, Moscow[2,3] show evidence of fast pulsed ion beams created near the critical surface. We will present calculations which support this interpretation by Pashinin, and show more detailed agreement with their reported observations. Possible implications will be discussed.

1) V.E.Zakharov et al ., *Sov. Phys. JETP.*, 69, 334 (1989).
2) P. P. Pashinin, US/USSR Workshop on Optical and Plasma Physics, Irvine, CA, (26-30 March 1990).
3) V. L. Artsimovich et al., *Sov. Phys. JETP*, 62, 1167 (1985).

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OBSERVATION AND ANALYSIS OF UP AND DOWN-SHIFTED STIMULATED RAMAN SCATTERING IN BACKWARD DIRECTION

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In many experiments the Raman backscattering has been evidenced by recording the down-shifted (Stokes) light. Up to now, the up-shifted (anti-Stokes) light in the backward direction has received very little attention. Since the wavenumber of the plasma wave (k_{epw}) is close to, or larger than the wavenumber (k_0) of the incident light, the up-shifted component is nonresonant and is generally neglected in the dispersion relation; so, its intensity is therefore predicted to be very low if one only considers the anti-Stokes light produced by the Raman process itself.

We have used the second harmonic of the neodymium laser of the LULI to irradiate preformed homogeneous underdense plasmas ($n_e \sim 0.1 n_c$). We report on the time-resolved spectra and intensities measurements of the up and down-shifted components of the backward Raman scattering. These two components appear to be correlated in time and symmetrically shifted by the plasma frequency (ω_p), from the fundamental laser frequency (λ=0.53μm) at any one time. The ratio of up versus down-shifted component intensities is high compared to what is expected from the linear theory.

We show that the ratio of the up-shifted component intensity to the laser intensity is an in-situ measurement of the electron density fluctuation associated to the plasma wave produced by the Raman instability. The interpretation of the ratio of up versus down-shifted component intensities need to take into account non-linear effects such as plasma wave mode coupling or plasma wave turbulence due to coupling with ion waves. These mechanisms reduce the Raman growth rate and the analysis of the anti-Stokes line should be useful to study the saturation of this instability.

Experiments to measure low-gain processes in laser-produced plasmas

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Laser-plasma instabilities can constrain the design of high-gain targets for laser fusion, by imposing limitations on laser wavelength, laser intensity, target material, and target size. This has led to extensive experimental studies of such instabilities during the past decade. However, many of the mechanisms that have been readily observed are arguably affected by coupling mechanisms and reflections at the critical and quarter-critical surfaces. Once the large, strongly-absorbing plasma has developed in a high-gain target, the critical and quarter-critical surfaces will have little impact on the laser-plasma interaction. During most of the laser pulse it will be the low-gain instability mechanisms, largely thought to be convective, that will constrain the target design. Such mechanisms include stimulated Raman forward, Brillouin, and Compton scattering. One important problem for the next generation of laser-plasma experiments is to quantitatively assess our ability to calculate such constraints. In the present talk, we will discuss the problem of designing an experiment to accomplish this end, and the initial phases of the implementation of one such experiment.

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