UNIVERSITY OF CALIFORNIA National Laboratories

47th Annual Anomalous Absorption Conference
Florence, Oregon
June 11-16th, 2017

47th Annual Anomalous Absorption Conference

JUNE 11-16, 2017 · DRIFTWOOD SHORES · FLORENCE, OR

❖ Morning Session ❖
Pacific Room

9:00AM	Heat Transport
11:10AM	Transport & Implosions I

❖ Evening Session ❖
Pacific Room

7:00 PM	Review Talk A.B. Sefkow, LLE

❖ Poster Session ❖
Pacific Room

8:00 PM	Poster Session
10:00 PM	Adjourn

❖

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2017 Anomalous Absorption Conference Program Agenda

Sunday, June 11, 2017 Sunset Board Room

	6:00 PM	Reception

Monday, June 12, 2017 Pacific Room

	8:00 AM - 9:00 AM	Breakfast
	9:00 AM	Welcome *D. E. Hinkel, Lawrence Livermore National Laboratory*
Oral Session:	*Heat Transport*	*Chair: D. P. Turnbull, Laboratory for Laser Energetics*
MoI-1	9:10 AM	A comparison of non-local electron transport models relevant to inertial confinement fusion *Presented by M. W. Sherlock, Lawrence Livermore National Laboratory*
MoO-1	9:40 AM	A return [current instability] visit to the NIC empty hohlraums of 2009, to the Omega Au spheres of 2006, and to NIF ignition scale hohlraums *Presented by M. D. Rosen, Lawrence Livermore National Laboratory*
MoO-2	10:00 AM	Proposing new Thin-Au-Coating Sphere experiments on the OMEGA Laser *Presented by D. Shvarts, University of Michigan*
MoO-3	10:20 AM	Incorporating kinetic effects on magnetized transport in inertial fusion *Presented by J. P. Brodrick, University of York*
	10:40 AM	Break
Oral Session:	*Transport & Implosions I*	*Chair: R. C. Nora, Lawrence Livermore National Laboratory*
MoO-4	11:10 AM	Comparison of simulated and measured temperatures inside a NIF hohlraum *Presented by W. A. Farmer, Lawrence Livermore National Laboratory*
MoI-2	11:30 AM	Revolver: a low fuel convergence path to ignition on the NIF *Presented by M. J. Schmitt and K. Molvig, Los Alamos National*
MoO-5	12:00 PM	Unprecedented stability in Z-pinch implosions due to magnetic fields and plasma physics *Presented by A. B. Sefkow, Laboratory for Laser Energetics*
	12:20 PM	Pick up box lunches

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Monday, June 12, 2017 Pacific Room

Oral Session:	*Review Talk*	*Chair: K. Peterson, Sandia National Laboratories*
MoR-1	7:00 PM	Adventures in ICF and HEDP with magnetic fields *Presented by A. B. Sefkow, Laboratory for Laser Energetics*
Poster Session:	8:00 PM - 10:00 PM	
MoP-1		Memorial to Tudor Wyatt Johnston *Presented by D.E. Hinkel, Lawrence Livermore National Laboratory*
MoP-2		Interplay between laser plasma interactions and heat transport *Presented by W. L. Kruer, Lawrence Livermore National Laboratory*
MoP-3		pF3D Simulations of LPI in NIF Hohlraums *Presented by S. H. Langer, Livermore National Laboratory*
MoP-4		Integrated simulations of hohlraums and capsule implosios in the NIF Marble platform *Presented by R. E. Olson, Los Alamos National Laboratory*
MoP-5		First 2D integrated simulations of NIF ignition targets including the tent support mechanism *Presented by J. L. Milovich, Lawrence Livermore National Laboratory*
MoP-6		Simulating 3D imprint from optically smoothed lasers *Presented by A. J. Schmitt, US Naval Research Laboratory*
MoP-7		M*shock* : A Richtmyer-Meshkov Experiment at OMEGA *Presented by T. Desjardins, Los Alamos National Laboratory*
MoP-8		A First-Principles Equation-of-State Table of Beryllium for High-Energy-Density Plasma Simulations *Presented by Y. H. Ding, Laboratory for Laser Energetics*
MoP-9		Picosecond thermal dynamics in an underdense plasma measured with Thomson scattering *Presented by A. Davies, Laboratory for Laser Energetics*
MoP-10		Proof of principle experiments on OMEGA for studying transport of supersonic radiation fronts in doped foams on NIF *Presented by H. M. Johns, Los Alamos National Laboratory*
MoP-11		Study of the plasma shock front structure in low-density systems *Presented by R. Hua, University of California, San Diego*

A comparison of non-local electron transport models relevant to inertial confinement fusion

M. Sherlock[1], J.P.Brodrick[2], C.P.Ridgers[2]
1. Lawrence Livermore National Laboratory, Livermore, CA 94551, USA
2. University of York, York, UK

We compare the reduced non-local electron transport model developed by Schurtz *et al*. (Phys. Plasmas 7, 4238 (2000)) to Vlasov-Fokker-Planck simulations. Two new test cases are considered: the propagation of a heat wave through a high density region into a lower density gas, and a 1-dimensional hohlraum ablation problem. We find the reduced model reproduces the peak heat flux well in the ablation region but significantly over-predicts the coronal preheat. The suitability of the reduced model for computing non-local transport effects other than thermal conductivity is considered by comparing the computed distribution function to the Vlasov-Fokker-Planck distribution function. It is shown that even when the reduced model reproduces the correct heat flux, the distribution function is significantly different to the Vlasov-Fokker-Planck prediction. Two simple modifications are considered which improve agreement between models in the coronal region.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

References

[1] G.P.Schurtz et al., Phys. Plasmas 7, 4238 (2000).

A return [current instability] visit to the NIC empty hohlraums of 2009, to the Omega Au spheres of 2006, and to NIF ignition scale hohlraums.*

Mordecai D. ROSEN [1], Mark W. SHERLOCK [1], Howard A. SCOTT [1] and George B. ZIMMERMAN [1]
1) Lawrence Livermore National Laboratory, USA

The first full energy shots on the National Ignition Facility (NIF) were into empty cylindrical Au hohlraums, performed in the summer of 2009 [1]. This was the beginning of the National Ignition Campaign (NIC). The hohlraum drive, derived from the x-ray emission emerging from the laser entrance hole, was measured by the broad-band multi-channel Dante x-ray detector. The drive was surprisingly high when compared to pre-shot simulation predictions, which used an average atom XSN non-LTE model along with a restrictive flux limiter, f, of 0.05 [2]. That value of f was a traditional one, based on decades of experimental analysis. A High Flux Model (HFM) [3] using a detailed configuration accounting DCA atomic physics model [4], and a more liberal flux limit of 0.15, (or its functional equivalent, a non-local model [5]), matched the data much better. As the data analysis was further refined, the HFM was found to slightly overestimate the drive [2]. Now, eight years later, we re-do those calculations with the latest DCA model, to see what electron transport model fits best. An f=0.05 flux limited model is somewhat too low, and the f=0.15 model is somewhat too high. We apply a newly implemented in-line model that incorporates estimates of the effects of enhanced scattering from the ion acoustic turbulence resulting from the return current instability (RCI), on both enhanced ("anomalous") absorption as well as on effective flux limitation [6], and we find that this in-line RCI can match the 2009 NIC empty hohlraum drive data. We also show that the same computational model can come close to explaining the 2006 Au sphere x-ray emission results, taken at the URLLE OMEGA laser in 2006 [7]. We also discuss the possible implications of RCI for ignition scale hohlraums.

References

[1] Kline et al PRL **106**, 085003 (2011)
[2] Olson et al Physics of Plasmas **19**, 053301 (2012)
[3] M.D. Rosen, et al, HEDP **7**, 180 (2011)
[4] H. Scott and S. Hansen, HEDP **6**, 39 (2010)
[5] G. Schurtz, X. Nicolai and M. Busquet, Phys. of Plasmas **7**, 4238 (2000)
[6] V. Yu. Bychenkov and W. Rozmus, Phys. of Plasma **24**, 012701 (2017)
[7] E. L. Dewald, M. D. Rosen, S. Glenzer, et al, Phys. of Plasma **15**, 072706 (2008)

* This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC
LLNL-ABS-728719

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Proposing new Thin-Au-Coating Sphere experiments on the OMEGA Laser

D. SHVARTS[1],K.H. MA[1], E. RAICHER[2], M. BEN-DOV[2],
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Experiments performed by LLNL on OMEGA studying X-ray conversion efficiencies for high-Z materials, aimed to confirm hohlraum modeling, resulted in a "liberal" flux limiter value of 0.15 to match simulations with these measurements [1][2]. This conclusion was re-examined and another model accounting for the effect of Ion Acoustic Turbulence on the thermal electron flux limitation and laser absorption was proposed, which better fits Hohlraum dynamics [3]. New experiments, using thin Au-coatings (0.1-0.5mic) instead of thick (7mic) Au layers, are proposed to explore time dependent Thermal (0-2KeV) and M-band (2-4KeV) emissions for Au-Coating thickness, flux limiter, and laser absorption model. These new experiments are expected to add more restrictions to the development of new models.

*Supported by the LLNL under subcontract B614207 to DE-AC52-07NA27344

[1] E.L. Dewald, et al., Phys. of Plasmas 15, 072706 (2008).
[2] M.D. Rosen et al., High Energy Density Physics 7, 180-190 (2011).
[3] M.D. Rosen et al., presented at the 2015 APS/DPP conference.
[4] Y. Frank et al., Phys. Rev. E 92, 053111 (2015).

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Incorporating kinetic effects on magnetized transport in inertial fusion simulations

J. P. Brodrick,[a]* M. Sherlock,[b] A. S. Joglekar,[c] R. A. Barrois,[d] J. T. Godroyd,[e] J. J. Bissell,[f] R. J. Kingham,[g] M. Read,[a] and C. P. Ridgers[a]

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Inhibition of heat transport by magnetic fields can allow for hotter hohlraum fill in inertial fusion experiments.[1] This advantage is somewhat diminished by the Nernst effect, which advects magnetic fields down temperature gradients.[2] Direct-drive simulations require flux-limiters on the Nernst term to match experimental measurements;[3] the same is likely to be true with indirect-drive. However, introducing another free parameter into design codes is undesirable; we therefore suggest three possible methods for incorporating corrections to the Nernst term motivated by comparisons with Vlasov-Fokker-Planck simulations: (a) obtaining independent fits for the Nernst and thermal flux-limiters as a function of magnetization (b) tying the Nernst flux-limiter to the thermal flux-limiter, and (c) tying the Nernst velocity directly to the heat flow, which could instead be obtained by an existing nonlocal model.[4]

This work is funded by EPSRC grant EP/K504178/1 and EP/M011372/1, and carried out within the framework of the EUROfusion Consortium receiving funding from Euratom under grant agreement No 633053 (project reference CfP-AWP17-IFE- CCFE-01).

[1] D. J. Strozzi *et al. J. Plasma Phys.* **81** (2015) [2] W Farmer *et al. APS Meeting Abstract* (2016)
[3] J R Davies *et al. Phys. Plasmas* **22** (2015) [4] G P Schurtz *et al. Phys. Plasmas* **7** (2000)

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Comparison of simulated and measured temperatures inside a NIF hohlraum

W. A. Farmer, O. S. Jones, J. M. Koning, M. A. Barrios Garcia, D. E. Hinkel, and D. J. Strozzi
Lawrence Livermore National Laboratory

The accurate simulation of hohlraum plasma conditions is important for predicting the partition of energy between x-ray drive, unabsorbed laser-light (lost either by backscatter through laser-plasma interactions or glint), and energy stored in the hohlraum plasma. Differences in plasma temperature can also affect where the laser energy is deposited, impacting the symmetry of the subsequent capsule implosion. Electron heat transport within the hohlraum plasma is difficult to model due to the complex interaction of kinetic plasma effects, magnetic fields, laser-plasma interactions, and microturbulence. Here, we compare simulations using the radiation-hydrodynamic code, HYDRA, to hohlraum plasma experiments which contain a Mn-Co tracer dot [1]. In these experiments, the dot is placed either on the capsule or on a film midway between the capsule and the laser-entrance hole (LEH). From spectroscopic measurements, both the temperature and position of the dot can be determined. We explore the effects of physical mechanisms such as flux limiting, magnetohydrodynamics, and nonlocal heat flow on the dot dynamics, and assess the correspondence to experimental data.

[1] M. A. Barrios Garcia, et al., Phys. Plasmas 23, 056307 (2016).

* This work was performed under the auspices of the U.S. DOE by Lawrence Livermore National Security, LLC, Lawrence Livermroe National Laboratory under Contract DE-AC52-07NA27344.

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Revolver: A low fuel convergence path to ignition on the NIF*

Mark J. Schmitt and Kim Molvig
Los Alamos National Laboratory

A novel concept for achieving ignition on the National Ignition Facility (NIF) is proposed[1] that obviates current issues plaguing single-shell high-convergence capsules. A large directly-driven Be shell is designed to robustly implode two nested internal shells by efficiently converting 1.7MJ of laser energy from a 6 ns, low intensity laser pulse, into a 1 ns dynamic pressure pulse to ignite and burn a central liquid DT core after a fuel convergence of only 9. The short, low intensity laser pulse mitigates laser plasma instabilities allowing more uniform laser drive of the target and eliminates hot electron, preheat and laser zooming issues. Preliminary rad-hydro simulations predict ignition initiation with 90% maximum inner shell velocity, before deceleration Rayleigh-Taylor growth can cause significant pusher shell mix into the compressed DT fuel. The gold inner pusher shell reduces pre-ignition radiation losses from the fuel allowing ignition to occur at 2.5keV. Further 2D simulations show that the short pulse design results in a spatially uniform kinetic drive that is tolerant to variations in laser cone power. A multi-pronged effort, in collaboration with the U. Rochester's Laboratory for Laser Energetics, is proposed to optimize this design for the polar direct drive laser configuration currently available on the NIF.

[1]Kim Molvig, Mark J. Schmitt, B. J. Albright, E. S. Dodd, N. M. Hoffman, G. H. McCall, and S. D. Ramsey, *Low fuel convergence path to direct-drive fusion ignition*, Phys. Rev. Lett. **116**, 255003 (2016).

* Work performed under the auspices of the U.S. Dept. of Energy by the Los Alamos National Security, LLC, Los Alamos National Laboratory under contract DE-FG02-051ER54810.

Unprecedented stability in Z-pinch implosions due to magnetic fields and plasma physics

A. B. Sefkow[1], J. M. Koning[2], M. R. Gomez[3], S. B. Hansen[3], K. Cochrane[3], C. Thoma[4], D. R. Welch[4], and M. M. Marinak[2]

[1]Laboratory for Laser Energetics, University of Rochester, Rochester, NY
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Fast z-pinch implosion dynamics have historically been plagued by low convergence ratio and compression due to the rapid growth of azimuthally-correlated (m=0) magneto-Rayleigh-Taylor instabilities, whose seed and mode structure remain generally unexplained from first principles. Magnetized liner implosions for MagLIF experiments [1, 2] have inferred convergence ratios in excess of 40 from x-ray self-emission spectroscopy [3] and backlit x-ray radiography [4, 5]. The unprecedented stability is enabled by the observed helical (m=1) modes and reduction of the most unstable m=0 mode present in all pulsed-power loads without applied axial magnetic fields. The correlated perturbations early in time are due to plasma particle bombardment from the transmission line that delivers the current to the load. Detailed calculations that account for the effect quantitatively produce the mode structure present in experimental radiographs of both magnetized and unmagnetized implosions, and furthermore explain the additional stability enjoyed by magnetized liners coated with thin layers of insulating material [5]. The improved understanding of implosion stability indicates the initial liner aspect ratios presently used (r/dr ~6-12) are very conservative, and values in excess of 20 should also be able to stably achieve their intended stagnation pressures. In fully integrated simulations of MagLIF experiments, we find: (1) favorable comparison between modeling and the observables, (2) the implosions efficiently produce the intended stagnation pressures, and (3) the hot spot is not dominated by 3D instability or mix for some of the best performing targets.

[1] A. B. Sefkow, et. al., *Phys. Plasmas* **21**, 072711 (2014); [2] M. R. Gomez, et. al., *Phys. Rev. Lett.* **113**, 155003 (2014); [3] S. B. Hansen, et. al., *Phys. Plasmas* **22**, 056313 (2015); [4] T. J. Awe, et. al., *Phys. Rev. Lett.* **111**, 235005 (2013); [5] T. J. Awe, et. al., *Phys. Rev. Lett.* **116**, 065001 (2016).

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Adventures in ICF and HEDP with magnetic fields

A. B. Sefkow[1], on behalf of a joint collaboration between LLE[1], LLNL[2], SNL[3], LANL[4], GA[5], and VS[6]
[1]*Laboratory for Laser Energetics, University of Rochester, NY, USA*
[2]*Lawrence Livermore National Laboratory, Livermore, CA, USA*
[3]*Sandia National Laboratories, Albuquerque, NM, USA*
[4]*Los Alamos National Laboratory, Los Alamos, NM, USA*
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[6]*Voss Scientific LLC, Albuquerque, NM, USA*

We are building a national program composed of groups using magnetic fields to relax inertial fusion stagnation pressure requirements and study the properties of extreme states of matter. The three main approaches to ICF being pursued by the US DOE are laser-driven indirect drive, laser-driven direct drive, and pulsed-power-driven direct drive, and the use of strong magnetic fields is being studied within the context of all three. For pulsed-power-driven MagLIF targets on the Z Machine [1-3], an imposed axial magnetic field is responsible for generating unprecedented implosion stability in metallic liners and is flux-compressed to nearly 100 MG with $R_{hot\text{-}spot}/R_L^{\alpha} < 1$ at stagnation, providing B_zR (instead of ρR) confinement of fusion-produced alpha particles. Magnetized laser-preheat experiments on OMEGA EP [4-5] and NIF study the coupling of laser energy to magnetized gas-filled surrogate targets in order to provide insight into near-term (E_{laser}~2-6 kJ) and long-term high-gain (E_{laser}~30 kJ) MagLIF physics. For direct-drive targets on OMEGA, magnetic fields are used in laser-driven direct-drive cylindrical targets in an approach called mini-MagLIF. The targets are premagnetized and preheated in order to reduce the implosion velocity and convergence ratio required to reach fusion-relevant stagnation conditions, and produce magneto-inertial fusion physics data. For indirect-drive hohlraum targets on OMEGA [6] and NIF, magnetic fields provide hotter plasmas, increased energy coupling, and reduced ρR and P_{stag} requirements in the hot spot. On OMEGA and OMEGA EP, plans are underway to provide 30-100 T applied magnetic fields to targets for ICF and HEDP research, and laser-driven coil targets [7] may provide 200 T or more. Our poster will survey these recent developments.

References

[1] A. B. Sefkow, S. A. Slutz, J. M. Koning, et. al., “Design of magnetized liner inertial fusion experiments using the Z facility”, *Phys. Plasmas* **21**, 072711 (2014).
[2] M. R. Gomez, S. A .Slutz, A. B. Sefkow, et. al., “Demonstration of thermonuclear conditions in magnetized liner inertial fusion experiments”, *Phys. Plasmas* **22**, 056306 (2015).
[3] S. B. Hansen, M. R. Gomez, A. B. Sefkow, et. al., “Diagnosing magnetized liner inertial fusion experiments on Z”, *Phys. Plasmas* **22**, 056313 (2015).
[4] A. J. Harvey-Thompson, A. B. Sefkow, M. S. Wei, et. al., “Laser propagation measurements in long-scale-length underdense plasmas relevant to magnetized liner inertial fusion”, *Phys. Rev. E.* **94**, 051201(R) (2016).
[5] A. J. Harvey-Thompson, A. B. Sefkow, T. N. Nagayama, et. al., “Diagnosing laser-preheated magnetized plasmas relevant to MagLIF”, *Phys. Plasmas* **22**, 122708 (2015).
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[7] J. J. Santos, M. Bailly-Grandvaux, L. Giuffrida, et. al., “Laser-driven platform for generation and characterization of strong quasi-static magnetic fields”, *New J. Phys.* **17**, 083051 (2015).

Remembering Tudor Wyatt Johnston*

D. E. Hinkel[1], W. B. Mori[2], F. Vidal[3], E. A. Williams[1]
[1]*Lawrence Livermore National Laboratory*
[2]*University of California, Los Angeles*
[3]*Centre for Energy of Institut National de la Recherche Scientifique*

Tudor Wyatt Johnston was a great scientist, teacher, sailor, mentor and friend. He leaves behind a memorable scientific and human legacy.

Trained in engineering (B.Eng. McGill, 1953; PhD Cambridge, 1958) Tudor was an outstanding physicist who made extensive original contributions to the theory of plasmas. After working in a private laboratory (RCA) in Montreal and then for a few years at the University of Houston, Tudor joined the Centre for Energy of Institut National de la Recherche Scientifique (INRS) in 1973 and founded the group “interaction laser-matiere”.

Consistent with his broad scientific interests, Tudor collaborated with colleagues on many different projects. Still highly regarded today is his acclaimed book “Particle Kinetics of Plasmas”. He authored/co-authored over 160 journal articles, including 23 in Physical Review Letters. He was instrumental in bringing the book “Survival Skills for Scientists” to the level of a bestselling text on professional development. He remained active until a few years ago and after officially retiring in 2010, became Emeritus Professor at INRS in 2012.

Due to his original contributions to physics and penetrating insights, Tudor was a plasma scientist whose stature was widely recognized internationally. He was in high demand as a consultant at numerous US institutions, associate divisional editor for major journals as well as a collaborator who was able to interpret complex experimental results and develop imaginative models with predictive properties. His work received ample peer recognition, and among various honors is his election to Fellow of the American Physical Society in 1968.

Tudor had an incredibly lively (and loud) personality. He could talk for hours about almost anything, yet he was also a very good listener. He was always full of ideas, eager to help, extremely generous with his time and provided constant stimuli to so many of us. Mentoring and helping others, especially younger colleagues and students in writing better papers and projects, was his second nature. His interests were broad well beyond science and his presence could fill a room with energy and enthusiasm.

Tudor also had a special influence on the Anomalous Absorption Conference. His impact was much greater than from his own publications. He had boundless energy and would ask a question after every talk, and his questions or comments were always insightful and useful. He was particularly supportive of students and post-docs at the conference and he greatly enjoyed hanging out with them. He selflessly gave suggestions and through his broad historical perspective of the subject matter would point you towards earlier publications or relevant analytical techniques that were not always well known. He has set a great example for us all.

* Work performed under the auspices of the U.S. Dept. of Energy by the Los Alamos National Security, LLC, Los Alamos National Laboratory under contract DE-FG02-051ER54810.

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Interplay between laser plasma interactions and heat transport*

William L. Kruer^ and Cliff Thomas
Lawrence Livermore National Laboratory

Abstract

Laser plasma interactions and heat transport are challenging and *coupled* issues for ICF target design. They each involve kinetic physics, various plasma instabilities, and self-generated magnetic fields. The laser energy deposition (and the hydrodynamics) is sensitive to the plasma temperature, which depends on the heat transport. For ICF-relevant energy fluxes the heat transport is typically in a regime beyond the classical Spitzer description (1). It then depends on nonlocal effects, plasma instabilities driven by either return currents and/or anisotropy in the velocity distribution function, as well as self–generated magnetic fields. Some examples are given to illustrate the important effect of heat transport on inverse bremsstrahlung absorption as well as on stimulated Raman scattering. The interplay between the coupling processes and the heat transport underscores the importance of experiments (2) using Thomson scattering techniques to characterize the plasma conditions and the amplitudes and frequencies of unstable plasma fluctuations. Some important topics for future detailed experiments are discussed.

1. V. Bychenkov and W. Rozmus, Phys. Plasmas 24, 012701 (2017) and references therein.
2. D. Froula, et. al., Phys. Rev. Lett. **93**, 035001 (2004)

^ Consultant LLNL

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pF3D Simulations of LPI in NIF Hohlraums

Steve Langer, Dick Berger, Tom Chapman, Oggie Jones
Lawrence Livermore National Laboratory

National Ignition Facility (NIF) ignition experiments have laser intensities high enough and length scales high enough that significant levels of backscattered light can occur[1]. The backscattered light reduces the x-ray drive, changes the drive symmetry, and (in extreme case) may damage the laser optics. The ignition program has recently begun to investigate a variety of innovative hohlraum designs. These designs must be assessed to make sure that LPI levels will be acceptable. pF3D is a massively parallel code that simulates LPI in NIF experiments using a paraxial approximation[2,3,4]. It is used to assess LPI risks and to help interpret experimental data. We discuss our plans to use pF3D to study these new hohlraum designs.

This talk describes recent changes to pF3D to make it easier to set up new simulations and to speed up the generation of comparisons between simulations and experiments. Computer architectures are changing significantly as the industry plans for future exascale systems. We discuss changes made to pF3D to allow it to exploit future computer systems and provide some preliminary results on the performance impact of these changes.

Work performed under the auspices of the U.S. Department of Energy by LLNL under Contract DE-AC52-07NA27344. Release number LLNL-ABS-730609.

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1) D. E. Hinkel, M. D. Rosen, E. A. Williams, A. B. Langdon, C. H. Still, D. A. Callahan, J. D. Moody, P. A. Michel, R. P. J. Town, R. A. London, and S. H. Langer. Stimulated Raman scatter analyses of experiments conducted at the National Ignition Facility. Phys. Plasmas, **18**:056312, 2011.
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3) C. H. Still, R. L. Berger, A. B. Langdon, D. E. Hinkel, L. J. Suter, and E. A. Williams. Filamentation and forward Brillouin scatter of entire smoothed and aberrated laser beams. Phys. Plasmas, **7**(5):2023, 2000.
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* FOOTNOTE:

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Integrated simulations of hohlraums and capsule implosions in the NIF Marble platform*

R. E. Olson, T. J. Murphy, M. R. Douglas, B. M. Haines,
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The Marble platform at the National Ignition Facility (NIF) is used to quantify the influence of heterogeneous mix on fusion burn[1]. This platform utilizes a plastic (CH) capsule filled with a deuterated plastic foam (CD) with a density of a few tens of milligrams per cubic centimeter, with tritium gas filling the voids in the foam. The capsule is driven with a single shock implosion by X rays generated in a NIF near-vacuum hohlraum (NVH)[2]. Since the Marble platform employs a NVH, the time-dependent symmetry of the implosion can be controlled via dynamic beam phasing[3]. Preliminary Marble experiments have demonstrated the ability to employ dynamic beam phasing and obtain good predictive capability of time-resolved hot spot symmetry. To date, design of the Marble laser pulse shape has been constrained by NIF laser optics damage restrictions. Although the hot spot is quite round at the time of peak x-ray emission, there is a predicted (and observed) symmetry swing during the hot spot formation and thermonuclear burn. In recent series of experiments, a mitigation of symmetry swing has been attempted via a systematic reduction of inner cone fraction laser power, while remaining within the low laser optics damage constraints. A comparison of predicted and experimental gated X ray images of the hot spot in this experimental series will be presented. Going forward, a new 2-shock Marble platform is being designed. Integrated 2D simulations of a proposed 2-shock laser pulse, hohlraum, and Marble capsule implosion will also be discussed in this presentation.

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First 2D integrated simulations of NIF ignition targets including the tent support mechanism*

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The goal of the indirect drive inertial confinement fusion (ICF) program is to compress a layer of DT fuel encapsulated by a low-Z shell (currently plastic or high-density carbon) using x-rays generated by laser-beams striking the interior of a high-Z cavity (hohlraum). The capsule is held at the center of the hohlraum by two thin (15-110 nm) membranes ("tent") and the fuel is delivered by a fill-tube (~10 um diameter). Recent experimental measurements [1,2] have identified these features with introducing additional seeds of perturbations beyond what was originally expected. To improve the robustness of the target the ignition program is beginning to explore upgraded hohlraum designs to increase the energy coupled to the capsule (~ 1.5-2 x over the current levels). Understanding the existing and modern designs will require improvements on our current modeling techniques. Capsule-only computer simulations [3,4,5] have been performed to evaluate the impact of both tents and fill-tube on ICF ignition implosions. However, shadows of the laser beams by the filling structures as well as x-ray gold m-band (> 1.8 kev) asymmetries are not properly modeled. Integrated simulations of full ignition targets including all the engineering structures as well as capsule roughness has been a long-standing dream of the ICF program. In this paper, we will show our first attempts of 2D integrated modeling of hohlraums including the tent support mechanism. The fidelity of our computations will be analyzed and results will be shown. Comparisons with existing capsule-only simulations as well as with experimental data from the hydro-growth-radiography experiments [6] will be presented.

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Simulating 3D imprint from optically smoothed lasers*

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The production of small-scale perturbations in mass and displacement on the surface of a laser-driven target due to imperfections of the driving laser beam is known as imprint. The invention of optically- smoothed lasers [1] provided controlled illumination conditions that both reduce this imprint while providing control and understanding of the detailed structure of the driving laser. Previous simulations of imprint [2] were limited to 2D, and used reduced imprint models wherein the full spectrum of fluctuations in the plane orthogonal to the drive direction is projected to the single allowed transverse direction. Recent 3D simulations have removed this limitation [3], but field structure along the propagation direction continues to be ignored. Here we simulate laser imprint in 3D and additionally explore a new laser imprint model that includes the axial laser speckle pattern. We present and discuss this new model and examine the results of these 3D simulations. To validate the modeling, we simulate recent imprint experiments performed on the Omega-EP laser and the Nike laser that examined the reduction of imprinting due to very thin high-Z target coatings [4].

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Mshock: A Richtmyer-Meshkov Experiment at OMEGA

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The Richtmyer-Meshkov (RM) and Rayleigh-Taylor (RT) instabilities are hydrodynamic processes that can cause mixing of materials at interfaces and can lead to and couple to other secondary instabilities. In inertial confinement fusion (ICF), RM can be initiated on imperfect interfaces by the primary shock from the lasers impacting the ablator. This RM phase is generally followed by an RT phase near implosion deceleration and stagnation. Prior to the RT phase, reflected shocks from within the capsule or shocks from multi-shock laser-drives can re-shock the linearly growing RM unstable layer, leading to increased growth, mix and turbulence. *Mshock* is a new campaign at the University of Rochester's OMEGA facility, with the goal of scaling to the National Ignition Facility where multiple shock capabilities can be added. *Mshock* seeks to study the growth of and instability feedthrough in a thin, dense, RM-unstable layer from an initial shock and then a second re-shock, similar to what occurs in ICF capsules, but using a planar geometry. Inside a beryllium (Be) shock tube, a thin (40μm) high-density layer of CH (ρ=1 g/cc) is placed between two pieces of low density CH foam (ρ=100 mg/cc). Two laser sources are used to drive shocks from opposite ends of the cylindrical Be tube. The initial laser-driven shock generates the RM instability in the high-density layer, while the second drive is used to re-shock the layer 3 ns later. The high-density layer is doped with iodine such that x-ray radiography can be used to capture the resulting mix-width time history from before the first shock until well after re-shock. Initial results show a well-defined mix-layer that expands after the first shock and then re-compresses during the re-shock after which it then exhibits increased growth. There are also indications that pre-heat is strongly affecting the high-density layer, dependent on the layer material, dopant and doping level. Results of the mix layer growth rate are compared with the BHR[3] mix model implemented in the hydrodynamic code RAGE[1].

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* FOOTNOTE:

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A First-Principles Equation-of-State Table of Beryllium for High-Energy-Density Plasma Simulations

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Beryllium has been considered a superior ablator material for inertial confinement fusion (ICF) target designs because of its large hydroefficiency. An accurate equation-of-state (EOS) table of beryllium under extreme conditions is essential to reliable ICF designs. Based on density-functional theory calculations, we have established a wide-range beryllium EOS table of density $\rho = 0.001$ to $\rho = 500$ g/cm3 and temperature $T = 2000$ to 10^8 K. Our first-principles equation-of-state (FPEOS) table is in better agreement with widely used *SESAME* EOS table (*SESAME* 2023) than the average-atom *INFERNO* model and the *Purgatorio* model. For the principal Hugoniot, our FPEOS prediction shows ~10% stiffer behavior than the last two models at maximum compression. Although the existing experimental data (only up to 17 Mbar) cannot distinguish these EOS models, we anticipate high-pressure experiments at the maximum compression region should differentiate our FPEOS from *INFERNO* and *Purgatorio* models. Comparisons between FPEOS and *SESAME* for off-Hugoniot conditions show that both the pressure and internal energy differences are within ~20% between two EOS tables. By implementing the FPEOS table into the 1-D radiation–hydrodynamics code *LILAC*, we studied the EOS effects on beryllium shell target implosions. The FPEOS simulation predicts up to an ~15% higher neutron yield compared to the simulation using the *SESAME* 2023 EOS table.

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Picosecond thermal dynamics in an underdense plasma measured with Thomson scattering

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Field-ionized underdense plasmas have many promising applications within the laser-plasma interaction field: nuclear fusion, particle accelerators, X-ray sources, and laser plasma amplification. Having complete knowledge of the plasma dynamics is essential to establishing optimal parameters for a given application. Here picosecond-resolved Thomson scattering measurements have been used to determine the electron thermal dynamics of an underdense ($\sim 10^{19}$ /cm) H_2 plasma irradiated by a 60 ps 1053 nm laser pulse with an intensity of 2 x 10^{14} W/cm^2. The picosecond resolved spectra were obtained with a novel pulse-front tilt compensated streaked optical spectrometer. The electron temperature was observed to rise from an initial 5 eV to a density-dependent plateau in 23 ps. Simulation results indicate that inverse bremsstrahlung heating, radiative cooling, and radial conduction cooling all play an important role in modeling the thermal dynamics.

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Proof of principle experiments on OMEGA for studying transport of supersonic radiation fronts in doped foams on NIF

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Supersonic radiation flow and its transition to the subsonic regime is commonly observed in astrophysical systems. However, quantifying the propagation of radiatively driven heat fronts in supersonic regimes is challenging due to the need for exacting target tolerances and detailed knowledge of both the equation of state (EOS) and opacity of the material through which the radiation flows. Moreover, simultaneous measurements of both the temperature history and heat front position are required. Past experiments[1] have used absorption spectroscopy in chlorinated foam to measure the heat front arrival, but the use of Chlorine would be suboptimal for the higher material temperatures achievable on NIF. Another advantage of NIF's higher energy is that supersonic radiation flow experiments can be conducted in the diffusive regime.[2] Recent experiments on OMEGA have developed Ti-doped foam targets to facilitate mesurement of spatially-resolved temperature profiles via absorption spectroscopy.[3] The next evolution of this series of experiments utilizes Sc-doped foams to quantify the front's profile at lower material temperatures in order to observe thermal effects from the hohlraum's non-Planckian drive. LANL OPLIB[4] tables were obtained for use with PrismSPECT to enable accurate modeling of Sc-absorption spectra between 60-100eV[5]. Analysis of data from these experiments will be shown in order to demonstrate proof of principle for this method for diagnosing supersonic and transonic radiation fronts.

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Study of the plasma shock front structure in low-density system

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shock front is not a simple discontinuity as depicted in commonly used hydro codes but consists of self-generated fields [1]. To study the field structure, a quasi-planar platform using broadband proton radiography has been developed on OMEGA EP [2]. Three long pulse beams were used for shock initiation. Diagnostics as broadband proton Radiography to detect the field and a specially resolved x-ray spectrometer (VSG) to infer the shock parameters were applied. The data and modeling indicate a 330 V potential electric field was present at a 0.5 Mbar shock front and this field potential is positively related to the shock strength. Shock speed is provided straightforwardly by VSG data. Other parameters such as temperature and density are inferred by simulating the data using spect3D. For a shock generated in the gas containing high Z material Ne, strong shock preheat feature is seen by both the radiography and x-ray spectrometer.

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❖ Morning Session ❖
Pacific Room

9:00AM	MagLIF
10:00AM	Kinetics Effects I

❖ Poster Session ❖
Pacific Room

7:00 PM	Poster Session
9:00 PM	Adjourn

Tuesday, June 13, 2017 Pacific Room

	8:00 AM - 9:00 AM		Breakfast
Oral Session:	*MagLIF*		*Chair: A. J. Harvey-Thompson, Sandia National Laboratories*
TuO-1	9:00 AM		Progress in Preconditioning MagLIF fuel and its Impact on Performance *Presented by K. J. Peterson, Sandia National Laboratories*
TuO-2	9:20 AM		Experiments and Simulations of Laser-Driven Magnetized Liner Inertial Fusion *Presented by E. C. Hansen, Laboratory for Laser Energetics*
TuO-3	9:40 AM		Pre-Heat Optimization for Magnetized Liner Inertial Fusion at Sandia *Presented by M. Geissel, Sandia National Laboratories*
Oral Session:	*Kinetics Effects I*		*Chair: A. S. Joglekar, University of California, Los Angeles*
TuI-1	10:00 AM		Nonlinear and collisional physics of ion acoustic waves *Presented by T. D. Chapman, Lawrence Livermore National Laboratory*
TuO-4	10:30 AM		Resolving Controversies in Understanding Shock Structure in Multi-Ion Plasmas *Presented by B. D. Keenan, Los Alamos National Laboratory*
	10:50 AM		*Break*
TuO-5	11:20 AM		Influence of coupling on thermal forces and dynamic friction in plasmas with multiple ion species *Presented by G. Kagan, Los Alamos National Laboratory*
TuO-6	11:40 AM		Investigating ICF Capsule Yield Anomalies via Kinetic Simulations *Presented by A. N. Simakov, Los Alamos National Laboratory*
TuO-7	12:00 PM		Observation of a plasma wake echo using a relativistic electron bunch *Presented by C. J. Zhang, Univerxity of California, Los Angeles*
	12:20 PM		Pick up box lunches

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Tuesday, June 13, 2017 Pacific Room

Poster Session 7:00 PM - 9:00 PM

TuP-1	A hybrid kinetic/fluid formalism for multi-ion-species plasmas with high mass number ratio *Presented by O. Larroche, Commissariat à l'Energie Atomique*
TuP-2	*In situ* Neutron-Based Diagnostic of Solid Density Plasma and MeV Ion Beams Created by Collisionless Shocks *Presented by S. C. Wilks, Lawrence Livermore National Laboratory*
TuP-3	Simulation of Interpenetrating Plasmas in 1D with a Multifluid Approach *Presented by D. Ghosh, Lawrence Livermore National Laboratory*
TuP-4	Self-similar solutions for multi-species plasma mixing by diffusive transport *Presented by E. Vold, Los Alamos National Laboratory*
TuP-5	Ultrafast Dynamics of Optical Field-Ionized Plasmas *Presented by C-K Huang, University of California, Los Angeles*
TuP-6	Generating high brightness electron beams using density downramp injection in nonlinear plasma wave wakefields *Presented by T. Dalichaouch, University of California, Los Angeles*
TuP-7	Plasma kinetic effects on interfacial mix in one and two spatial dimensions *Presented by L. Yin, Los Alamos National Laboratory*
TuP-8	Particle-in-Cell Simulations of Laser Plasma Interactions in Multiple Speckles with Temporal Bandwidth *Presented by H. Wen, University of California, Los Angeles*
TuP-9	Designing and testing new preheat protocols for MagLIF *Presented by A. J. Harvey-Thompson, Sandia National Laboratories*
TuP-10	Magnetized Liner Inertial Fusion at Sandia: Time-Resolved Backscatter Spectra of the Pre-Heat Laser *Presented by D. E. Bliss, Sandia National Laboratories*
TuP-11	The Use of Surrogate Solid Fuels in NIF Double Shell Capsules *Presented by D. C. Wilson, Los Alamos National Laboratory*

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Progress in Preconditioning MagLIF fuel and its Impact on Performance

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The initial results of the magnetized liner inertial fusion (MagLIF) concept [1] at Sandia National Laboratories were successful at demonstrating key principles of magneto-inertial fusion: fuel pre-heating, pre-magnetization, and compression can work in concert to produce interesting thermonuclear stagnation conditions [2]. While, these results have been promising, significant challenges remain to test and determine realistic estimates of scaled performance. One of these challenges is a determining the initial conditions of the laser heated plasma and the evolution of those plasma conditions throughout the magnetically driven implosion. Empirical evidence suggests that only a small fraction of the delivered laser energy coupled to the fusion fuel in our initial experiments. Over the past year, significant experimental and computational work has been done to develop a new laser preheating platform with a goal of creating well understood and reproducible initial plasma conditions as well as to provide a baseline for increasing the coupled laser energy for future scaling tests. This talk will give an overview of the work that has been done to develop this platform and report on the performance results of using this new platform on integrated MagLIF experiments performed on the Z machine.

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Experiments and Simulations of Laser-Driven Magnetized Liner Inertial Fusion

E. C. HANSEN, D. H. BARNAK, J. R. DAVIES, R. BETTI, A. B. SEFKOW, J. PEEBLES, V. Yu. GLEBOV, J. P. KNAUER, E. M. CAMPBELL, and S. P. REGAN
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Magnetized liner inertial fusion (MagLIF) is a key concept in the field of magneto-inertial fusion (MIF). MagLIF can reduce the velocity, pressure, and convergence ratio required by typical inertial confinement fusion (ICF) schemes resulting from an axial magnetic field and preheating of the fuel. A pulsed-power platform of MagLIF is being studied at the Z Facility, and a scaled-down, laser-driven version (often referred to as mini-MagLIF) is being researched on OMEGA. The cylindrical, plastic mini-MagLIF targets have an outer diameter of approximately 0.6 mm and are filled with 2.4 mg/cm^3 of D_2 gas. A fully integrated shot on OMEGA uses 40 radial compression beams, one on-axis preheat beam, and the magneto-inertial fusion electrical discharge system (MIFEDS) to generate the axial magnetic field. Preheat to >100 eV has been demonstrated, and MIFEDS can produce fields of ~10 T. Four different types of shots have been completed: compression-only, compression and preheat, compression and field, and fully integrated. One-dimensional *LILAC* and 2-D *HYDRA* simulations have been utilized to model the experiments. In particular, synthetic x-ray self-emission images have been produced to compare to x-ray framing-camera images. By modeling the shape of the x-ray emission from the edges of the cylindrical shell, we were able to optimize the compression, thereby achieving compression uniformity over a 0.7-mm region. Analysis of the shell trajectories over time leads to calculated x-ray velocities that can be used as an additional measure of how well the simulations model the experiments. Experimental and simulation results of the aforementioned four types of shots are presented here.

This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944, the University of Rochester, and the New York State Energy Research and Development Authority. The support of DOE does not constitute an endorsement by DOE of the views expressed in this article.

Pre-Heat Optimization for Magnetized Liner Inertial Fusion at Sandia*

Matthias Geissel, A.J. Harvey-Thompson, T.J. Awe, D.E. Bliss, M.E. Glinsky, M.R. Gomez, E. Harding, S.B. Hansen, C. Jennings, M.W. Kimmel, P.F. Knapp, S.M. Lewis, K. Peterson, M. Schollmeier, J. Schwarz, J.E. Shores, S.A. Slutz, D.B. Sinars, I.C. Smith, C.S. Speas, R.A. Vesey, M.R. Weis, and J.L. Porter

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The size, temporal and spatial shape, and energy content of a laser pulse for the pre-heat phase of magneto-inertial fusion affect the ability to penetrate the window of the Laser-Entrance-Hole and to heat the fuel behind it. High laser intensities and dense targets are subject to laser-plasma-instabilities (LPI), which can lead to an effective loss of pre-heat energy or to pronounced heating of areas that should stay unexposed. While this problem has been the subject of many studies over the last decades, the investigated parameters were typically geared towards traditional laser driven Inertial Confinement Fusion with densities in excess of 10% of the laser's critical density, electron temperatures for 3-5 keV, and laser powers near (or in excess of) 1E15W/cm^2. We will describe the progress of laser pre-heat in Sandia's Magnetized Liner Inertial Fusion program[1,2] with the Z-Beamlet laser facility[3] by extending the study of Stimulated Brillouin Scattering and other LPI effects to larger spatial scales with lower densities, temperatures, and powers. The newest results from integrated MagLIF experiments will demonstrate the impact of these improved parameters to the Magneto-Inertial Fusion program at Sandia.

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* FOOTNOTE: Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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Estimates of the impact of heat flow on parametric instabilities in ICF hohlraums

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The local distribution function in a plasma with a heat flow is necessarily non-Maxwellian. The heat-carrying electrons have velocities at 3-4 times the thermal velocity, while the return current affects the distribution at much lower velocities. In laser-driven inertial confinement fusion (ICF) experiments, plasma waves excited by parametric instabilities see these modified distributions, and have frequencies and Landau dampings different to those expected in a Maxwellian plasma[1]. The impact of heat flow on the gain of the plasma for stimulated Raman scattering, stimulated Brillouin scattering, and cross-beam energy transfer of an incident laser are considered, as well as the spectrum of observable scattered light. Further modifications to the distribution due to the system boundaries (a high-Z wall and a sheath layer near the entrance to the hohlraum) and inverse-Bremsstrahlung heating of the plasma[2,3] are included in our simulations and calculations.

In this study, plasma conditions during ICF experiments are obtained from hydrodynamic simulations. These plasma conditions are fed into a Fokker-Planck calculation[4,5], which is allowed to reach a quasi-steady state. The gain for various LPI processes is then calculated based on the output of Fokker-Planck simulations.

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Resolving Controversies in Understanding Shock Structure in Multi-ion Plasmas*

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Strong collisional shocks in multi-ion plasmas are featured in several high-energy-density environments, including Inertial Confinement Fusion (ICF) implosions. Yet, basic structural features of these shocks remain poorly understood (e.g., the shock width's dependence on the Mach number and the plasma ion composition), causing controversies in the literature, even for stationary shocks in planar geometry[1]. Using the LANL-developed, high-fidelity, 1D-2V Vlasov-Fokker-Planck code (iFP)[2], as well as direct comparisons to full multi-ion hydrodynamic simulations and semi-analytic predictions, we critically examine steady-state planar shocks in D-^{3}He plasmas and put forward a resolution to these controversies. Additionally, we compare iFP simulations to relevant laboratory planar shock experiments.

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Influence of coupling on thermal forces and dynamic friction in plasmas with multiple ion species

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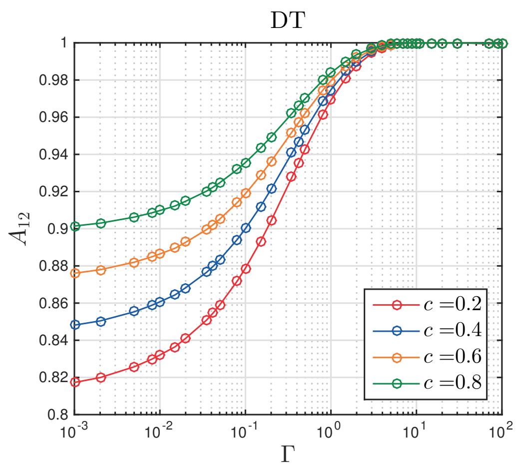
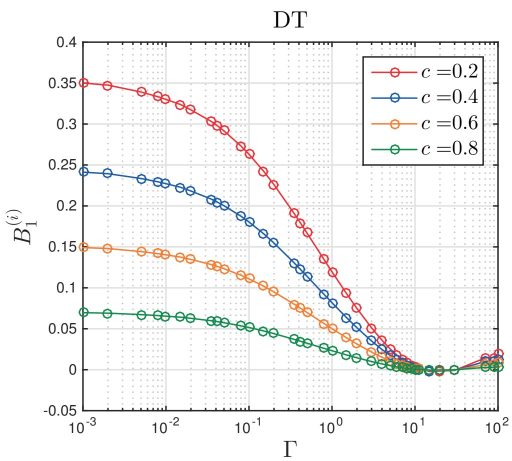
The recently proposed effective potential theory [1] is used to investigate the influence of coupling on inter-ion-species diffusion and momentum exchange in multi-component plasmas. Thermo-diffusion and the thermal force are found to diminish rapidly as strong coupling onsets. For the same coupling parameters, the dynamic friction coefficient is found to tend to unity. It should be contrasted with the case of the conventional, weakly coupled plasma, in which thermo-diffusion is comparable to, or even much larger, than baro-diffusion [2,3]. These findings provide an impetus for addressing the role of coupling on diffusive processes in inertial confinement fusion experiments [4].





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Investigating ICF Capsule Yield Anomalies via Kinetic Simulations*

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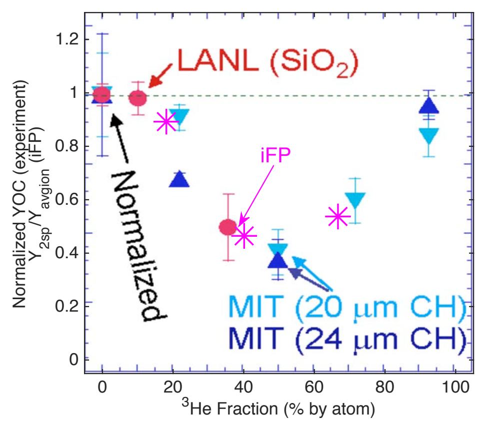
In the quest towards ICF ignition, plasma kinetic effects are among prime candidates for explaining discrepancies between experiments and rad-hydro simulations. To assess their importance, a high-fidelity code for fully kinetic simulations of ICF capsule implosions is needed. Owing to the exceedingly multiscale nature of the problem, such a code has to overcome nontrivial numerical and algorithmic challenges, and very few options are currently available.

Here, we present an assessment of the impact of kinetic fuel ion stratification on anomalous yield degradation using the novel, LANL-developed, 1D-2V Vlasov-Fokker-Planck code iFP [1] to model the implosion experiments discussed below. iFP is a multiscale code of unprecedented fidelity, featuring fully implicit time-stepping, exact mass, momentum, and energy conservation, and optimal grid adaptation in phase space, all critical to ensure long-time numerical accuracy of capsule implosion simulations.



Anomalous yield degradation has been observed in several Omega campaigns, with the so-called "Rygg effect" [2] being a prime example. Understanding the physical mechanisms responsible for such a degradation in non-ignition-grade experiments is of great interest, as such experiments are often used for platform and diagnostic development, which are extrapolated to ignition-grade experiments on NIF. Fuel ion stratification in the Rygg experiments has been previously studied with a kinetic code FPION [3], concluding that kinetic effects were not at play. We have revisited this issue with iFP and have found excellent yield-over-clean (YOC) agreement with several LANL and MIT experimental results. This validates iFP and suggests that the kinetic fuel stratification is indeed at the root of the observed yield degradation.

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Observation of a plasma wake echo using a relativistic electron bunch

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The recurrence of the plasma wake, i.e., an echo, in a plasma density upramp is observed for the first time by using a relativistic electron bunch generated from a laser wakefield accelerator. The relativistic, ultrashort features of such electron bunches open the possibility to capture the field structures of a relativistic plasma wake [1]. By using this technique, the temporal evolution of the plasma wake wavelength in a density upramp is recorded. It is found that after the laser driver has passed, the local wake wavelength first increases with time until it eventually tends to infinity, then it begins to shorten and the phase velocity of the wake reverses its direction. This echo has a different physical origin than the usual plasma echo [2] and only occurs in a density upramp. In a density downramp, the wake wavelength monotonically decreases as a function of time until it can eventually be damped by wave-particle interactions [3]. Both the existence of wake echo in a density upramp and its absence in a density downramp are theoretically explained and confirmed in particle-in-cell simulations.

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A hybrid kinetic/fluid formalism for multi-ion-species plasmas with high mass number ratio

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The interpretation of recent ICF capsule implosion experiments with moderate to high Knudsen numbers[1] has relied on ion-kinetic Vlasov-Fokker-Planck[2] (VFP) or particle-in-cell[3] numerical simulations. However, those calculations face a tough challenge in regions of the targets where the light elements of the fuel (H, D, T, ^{3}He) interact with the heavier elements of the capsule (including C, O, Si), leading to a strong collisionality contrast. As a result, in Ref. 2 the pusher was treated as a simple tamper, discarding possible diffusion effects across the fuel/pusher interface, while in Ref. 3 “brute force” was claimed to be a valid strategy, notwithstanding the very large computing time hence required.

In this work, we investigate a hybrid multi-species formalism in which the behavior of the heavier, more collisional elements is rendered through a set of hydrodynamical, few-moment equations while the lighter ones get a full kinetic treatment. A careful examination of the various collisional timescales involved demonstrates the theoretical validity of such an approach, and leads to a consistent kinetic treatment of the light species through adequately calculated Rosenbluth potentials[4] while the correct integrated relaxation terms are applied to the heavier ones. As a result, the smallest collision times, involving high-mass species only, don’t need to be resolved any more, releasing the related time-step constraint, while the intermediate, light-on-heavy, collision times, involving only a restricted volume of velocity space, should be amenable to a carefully tailored, locally-refined, explicit scheme[5].

The implementation of this formalism in the VFP code FPION[6] is underway and should be applied to, e.g., the structure of shock waves in CH plasmas or an improved treatment of the targets investigated in Ref. 2, where some discrepancies with experimental data was found in the highest-Knudsen-number (less collisional) cases.

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In situ Neutron-Based Diagnostic of Solid Density Plasma and MeV Ion Beams Created by Collisionless Shocks

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Lawrence Livermore National Laboratory

For almost 20 years, insight into ion acceleration from ultra-intense short pulse laser-solid interactions has been achieved via diagnostics external to the target (e.g. through RC film and ion spectrometers). These diagnostics have yielded considerable data about ions escaping the target, however virtually all the information collected thus far has been on the TNSA (Target Normal Sheath Acceleration) protons: that is, ions that are accelerated off the surfaces of the target. Simulations predict that keV ion temperatures might also exist inside the target, and there have been attempts to estimate temperatures from radiation spectra, but these rely heavily on assumptions of the hydro and plasma conditions and untested opacity tables. We propose using neutrons as a diagnostic of both the bulk flow and temperature of the heated solid density region. In this poster, predictions for neutron spectra based on PIC simulations will be presented, and diagnostic details will be discussed.

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Simulation of Interpenetrating Plasmas in 1D with a Multifluid Approach†

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Several plasma physics applications are characterized by the interaction of multiple flows. In inertial confinement fusion, plasma streams ablate from the hohlraum walls and the capsule and interpenetrate. High-energy density physics experiments involve the collision of plasma streams ablating off discs irradiated by laser beams. On one hand, numerical codes based on single-fluid, multi-species hydrodynamics[1] are not sufficient for such applications; they result in unphysical effects such as stagnation and strong shocks. On the other hand, kinetic codes[2,3,4] are prohibitively expensive for at-scale simulations.

In this poster, we present results for a 1D multifluid simulation tool. The Euler equations are solved for each ion species, and the electrostatic potential, inter-species friction, and thermal equilibration couple the dynamics of each species. Electrons are assumed to be inertia-less and isothermal. We extend a two-fluid code previously developed[5] to n-fluids. The 4th order Runge-Kutta method is used for time-integration while the 5th order Weighted Essentially Non-Oscillatory (WENO) scheme is used to discretize spatial derivatives. The 1D code is used to simulated the interpenetration of counter-streaming plasmas in vacuum as well as in the presence of a gas-fill.

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Self-similar solutions for multi-species plasma mixing by diffusive transport

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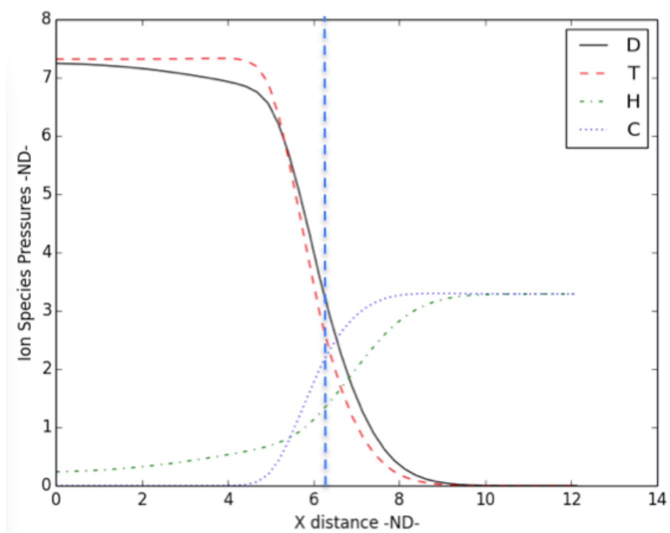
Diffusion is the kinetic process representing species mass transport, and is well known to have self-similar solutions in the limit of small Knudsen number. The self-similar solution for binary plasma mixing at an interface was examined in theory [1], in fluid simulations [2] and in kinetic simulations [3]. Multi-species forms for plasma transport have been described [4-5], and have been found to lead to identical transport coefficients. We have used these transport coefficients to evolve multi-species profiles during mixing across interfaces of relevance in ICF, with the basic test case being a fuel with equal moles of D and T mixing with a plastic of equal molar H and C, and with the fuel-capsule in total pressure equilibrium. The self-similar profiles at a late time for this case are shown in the figure. The physical diffusion width, L_D, for a constant diffusion coefficient is estimated as $L_D = (4D\,t)^{1/2}$ and a more general expression applies for time evolving diffusion coefficients.



In isothermal mixing, the kinetic results are shown to agree closely with a simpler Stephan-Maxwell formulation based on a momentum exchange time related to a classical ion slowing down time in a Maxwellian plasma. We plan to explore the differences in self-similar solutions under non-equilibrium conditions of relevance to ICF, e.g. in the pressure and temperature gradient conditions expected at burn time. These results will be related to plasma transport in fluid models [2] and in kinetic models [3] and may help predict mix effects in ICF performance.

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Ultrafast Dynamics of Optical-Field Ionized Plasmas

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Optical-field ionization has been shown to be an effective heating mechanism of plasmas when pumped by intense laser pulses [1]. The quasiclassical theory of tunnel ionization predicts a non-Maxwellian residual electron distribution when the pumping pulse is circularly polarized. The transition from the non-Maxwellian plasma distribution to a thermal plasma can take place in several hundreds of femtoseconds. In this report, we study the dynamics of plasma electrons produced by femtosecond intense laser pulses using a PIC code. An experiment has been proposed to use Thomson scattering in direct measurement of the residual electron distribution of optically ionized plasmas.

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Generating high brightness electron beams using density downramp injection in nonlinear plasma wave wakefields

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Fei Li, Wei Lu
Tsinghua, China

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BODY OF ABSTRACT

In the past few decades, there has been much progress in theory, simulation, and experiment towards using Plasma wakefield acceleration (PWFA) and Laser wakefield acceleration (LWFA) as the basis for designing and building compact x-ray free-electron-lasers (XFEL) as well as a next generation linear collider. Recently, ionization injection and density downramp injection have been proposed and demonstrated as controllable injection schemes for generating high quality relativistic electron beams. We present the concepts and full 3D simulation results using OSIRIS which show that downramp injection can generate electron beams with unprecedented brightness. However full-3D simulations of plasma-based acceleration can be computationally intensive, sometimes taking millions of cpu-hours. Due to the near azimuthal symmetry in PWFA and LWFA, quasi-3D simulations using a cylindrical geometry are computationally more efficient than 3D Cartesian simulations since only the first few harmonics are needed in ϕ to capture the 3D physics of most problems. We also present results from the quasi-3D approach on downramp injection and compare the results against full 3D simulations.

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Plasma kinetic effects on interfacial mix in one and two spatial dimensions*

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Mixing at interfaces in dense plasma media is a problem central to inertial confinement fusion and high energy density experiments. In this work, particle-in-cell VPIC simulations in one- and two-spatial dimensions (1D and 2D) with a binary collision model are used to explore kinetic effects arising during the mixing of plasma media. In 1D, comparisons [1] are made to the results of analytic theory in the small Knudsen number limit [2]. While the bulk mixing properties of interfaces are in general agreement, some differences arise, primarily near the low-concentration fronts of the diffusing ions during the early evolution of a sharp interface. The theory is strictly valid only in the limit of small Knudsen numbers and it predicts small diffusion velocities compared with the ion thermal speeds. In kinetic simulations, however, we found that the diffusion velocities can be larger or comparable to the ion thermal speeds, and the Knudsen number can be large; this occurs when the species' perpendicular scattering rate dominates over the slowing down rate. As a consequence, super-diffusive growth in mix widths ($\Delta x \sim t^a$ where $a \geq 1/2$) is seen before transition to the slow diffusive process ($\Delta x \sim t^{1/2}$) predicted from theory. Mixing at interfaces leads to persistent, bulk, hydrodynamic features in the center of mass flow profiles. This behavior arises as a result of the diffusion process and conservation of momentum. In other words, interfacial mixing inevitably generates modifications to the bulk hydrodynamics, a result that has not been examined extensively in prior studies. These conclusions are drawn from VPIC results together with simulations from the RAGE code [3] with an implementation of diffusion and viscosity from theory [2] and an implicit Vlasov-Fokker-Planck (iFP) code [4]. The applicability of the 1D ambipolarity criterion (from which theoretical plasma transport models have been derived) was evaluated in 2D VPIC simulations of a plasma interface with a sinusoidal perturbation. Kinetic effects on interfacial mix were also examined in 2D. Results of these studies, including comparisons with 1D kinetic models and with 2D RAGE calculations, will be presented and discussed.

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Particle-in-Cell Simulation of Laser Plasma Interactions in Multiple Speckles with Temporal Bandwidth

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Various laser-smoothing techniques have been implemented in inertial confinement fusion (ICF) applications to mitigate hydro-instabilities and laser-plasma instabilities. These laser-smoothing techniques introduce small-scale structures (speckles) with higher-than-average intensities. A general laser antenna has been implemented in particle-in-cell (PIC) code OSIRIS to model smoothing by spectral dispersion[1] (SSD), induced spatial incoherence[2] (ISI) and spike train of uneven duration and delay[3] (STUD) pulse. Preliminary results of stimulated Raman scattering (SRS) affected by different laser-smoothing techniques are discussed.

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Designing and testing new preheat protocols for MagLIF

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The MAGnetized Liner Inertial Fusion (MagLIF) scheme has achieved thermonuclear fusion yields on the Z Facility[1,2] by imploding a cylindrical liner filled with D_2 fuel that is preheated with a 0.53 μm multi-kJ laser and pre-magnetized with an axial B_z=10 T magnetic field. Preheating (T_e = 100-200 eV) and pre-magnetizing the fuel serves to reduce the implosion velocity (~10^7 cm/sec) required to achieve multi-keV fusion-relevant temperatures at stagnation with modest radial convergence (~20). Preheating the fuel requires coupling multiple-kJ of optical laser energy at modest intensities ($I\lambda^2$ ~10^{14} watts-μm^2 /cm^2) into long scale-length (L~10 mm) D_2 plasmas with initial fuel densities n_e/n_{crit}= 0.05-0.1.

Previous MagLIF experiments have used a defocused, unsmoothed beam to preheat the fuel which is now known to produce large quantities of stimulated Brillouin backscatter. Applying phase plate smoothing and lowering the beam intensity reduces this backscatter, potentially producing a more reproducible and understandable deposition profile. In order to successfully design new preheat protocols, separate laser-only experiments are conducted using MagLIF-like gas cells which aim to constrain energy deposition and backscatter. The new protocols are then used in integrated MagLIF experiments where initial results have been promising but inconsistent. Techniques for diagnosing mix from the laser-entrance-hole window have been applied in these experiments which show window material migrating into the imploding fuel, potentially degrading the yield and causing the observed irreproducibility of stagnation conditions.

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* Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

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Magnetized Liner Inertial Fusion at Sandia: Time-Resolved Backscatter Spectra of the Pre-Heat Laser[*]

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During magnetized liner inertial fusion (MagLIF) experiments at Sandia National Laboratories, a kilojoule class laser is used to pre-heat the deuterium fuel before compression. Laser-plasma-instabilities (LPI) result from the interaction of the high intensity laser with dense target materials such as the Laser-Entrance-Hole window, fuel and bottom-cap of the liner. The primary LPI modes observed are stimulated Raman scattering (SRS) and stimulated Brillouin scattering (SBS). If the parametric gain is great enough, >20, these stimulated processes become parasitic and can block nearly all of the laser pre-heat energy. Fortunately, we observe smaller gains, and the total backscattered light is <10%. An additional benefit of observing some low level backscatter is that the wavelength shift and intensity can be used as a diagnostic probe of the laser target interaction dynamics. SRS reveals the evolution of the electron plasma density while SBS indicates temperature. We will show how target and laser properties affect the time resolved backscatter spectra. Preliminary comparisons with Hydra calculations will be shown. Results are presented for laser-only experiments as well as fully integrated shots on Z.

*Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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The Use of Surrogate Solid Fuels in NIF Double Shell Capsules

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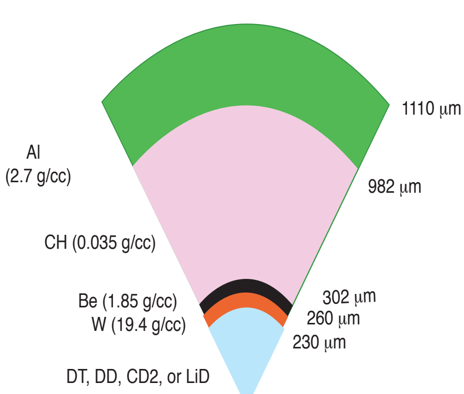
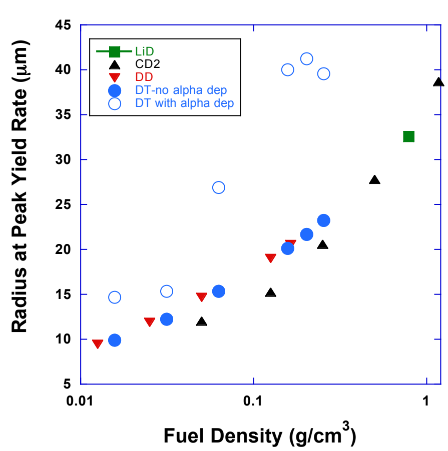
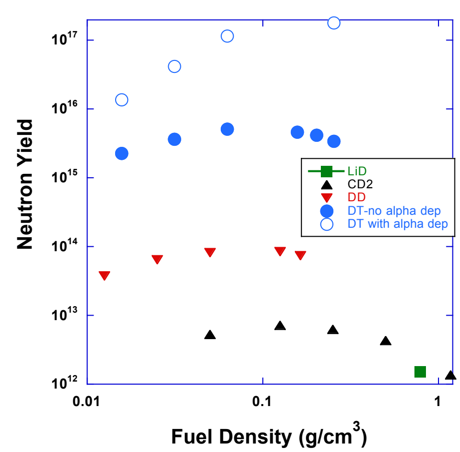
An ignition double shell target for NIF would contain a central high Z shell capsule with DT at near solid density. However filling that capsule introduces perturbations from a fill tube, or even a "peek" hole that can cause disastrous perturbations to the implosion (J. Milovich and P. Amendt, 2016, private communication). To study the impact of any fill feature we would like to understand implosions without it. Our current ignition design uses a tungsten inner shell, a surrounding tamper of beryllium, a CH foam cushion, and an aluminum ablator. Instead of liquid or gaseous DT early targets could contain a solid sphere over-coated with tungsten and beryllium. We have considered deuterated polyethlene (CD_2) and LiD as surrogate materials that could produce enough D+D neutrons to diagnose an implosion (~1e+12), and also allow lower convergence implosions to test double shell physics. Of particular interest are solid and 0.25 g/cc density CD_2 foam that converge to the same fuel radii as an igniting and a failed (no alphas deposited) DT capsule. The surrogate fuel density controls the convergence. A double shell target might be fabricated with an overcoat of tungsten, then beryllium, on a CD_2 sphere. The physics of double shell implosions could be studied at DT-like convergences, without the complication of any fill features. LA-UR-17-23546.







❖ Morning Session ❖
Pacific Room

9:00AM	SRS I
11:00AM	SRS II

❖ Evening Session ❖
Pacific Room

5:30 PM	Cocktail Hour Reception
6:00 PM	Banquet Dinner
8:00 PM	Fireside S’mores

❖

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Wednesday, June 14, 2017 Pacific Room

	8:00 AM - 9:00 AM	Breakfast
Oral Session:	*SRS I*	*Chair: L. Yin, Los Alamos National Laboratory*
WeI-1	9:00 AM	Multi-Speckle Stimulated Raman Scattering in External Magnetic Fields *Presented by B. J. Winjum, University of California, Los Angeles*
WeO-1	9:30 AM	Nonlinear Fluid Simulation Study of Stimulated Raman and Brillouin Scatterings in Shock Ignition *Presented by C. Ren, University of Rochester*
WeO-2	9:50 AM	Vlasov-Fokker-Planck modeling of enhanced SRS growth in semi-collisional, laser-heated plasmas relevant to ICF *Presented by A. S. Joglekar, University of California, Los Angeles*
WeO-3	10:10 AM	Investigation of stimulated Raman scattering driven by two or multiple, picosecond laser pulses *Presented by C. Rousseaux, Commissariat à l'Energie Atomique*
	10:30 AM	Break
Oral Session:	*SRS II*	*Chair: A. J. Schmitt, Naval Research Laboratory*
WeI-2	11:00 AM	Planar Laser-Plasma Interaction Experiments at Direct-Drive Ignition-Relevant Scale Lengths at the National Ignition Facility *Presented by M. J. Rosenberg, Laboratory for Laser Energetics*
WeO-4	11:30 AM	Measurements and modeling of Raman side-scatter in ICF experiments *Presented by P. A. Michel, Lawrence Livermore National Laboratory*
WeO-5	11:50 AM	Observation of Stimulated Raman Scattering and Two-Plasmon-Decay Instabilities on OMEGA and the National Ignition Facility *Presented by W. Seka, Laboratory for Laser Energetics*
WeO-6	12:10 PM	Absolute Stimulated Raman Scattering in Direct-Drive Irradiation *Presented by R. W. Short, Laboratory for Laser Energetics*
	12:30 PM	Business Meeting
	12:50 PM	Pick up box lunches
	5:30 PM	Banquet Reception
	6:00 PM	Banquet
	8:00 PM	Fireside Smores

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Multi-Speckle Stimulated Raman Scattering in External Magnetic Fields

B. J. Winjum, A. S. Tableman, F. S. Tsung, W. B. Mori
University of California, Los Angeles

The kinetic evolution of stimulated Raman scattering (SRS) is sensitively dependent on nonlinear wave-particle interactions. In the case of multi-speckled laser beams, the spread of waves and particles resulting from SRS in one above-threshold speckle can change the SRS threshold and saturation in neighboring speckles, giving rise to inter-speckle interactions and cascades of SRS that grow above single-speckle estimates. Using 2D PIC simulations, we show that an external magnetic field B_{ext} can reduce SRS activity in multi-speckled laser beams. First, by rotating resonant particles in velocity space and thereby disrupting the nonlinear damping of electron plasma waves, B_{ext} changes the threshold for kinetically inflated SRS and reduces the number of speckles that are above the laser intensity needed for kinetically inflated activity. Second, B_{ext} alters the transverse kinetic dissipation of electron plasma waves, reducing SRS reflectivity in those speckles that are above threshold. Third, the impact of SRS in above-threshold speckles on neighboring speckles is reduced, both because their production of scattered light waves and trapped particles is reduced and because it is more difficult to trigger SRS in neighboring below-threshold speckles since they are farther below threshold. Finally, the spatial range of trapped particles is confined more closely to existing regions of instability rather than being sprayed outward. In multi-speckled SRS, the spatial extent of collective cascades is restricted, due to the effect of B_{ext} on the kinetic SRS threshold, and SRS-generated plasma waves damp more quickly at a given spatial location due to the effect of B_{ext} on nonlinear plasma wave damping.

* This work was supported by the DOE under Grant Nos. DE-NA0001833 and DE-FC02-04ER54789. Simulations were carried out on the Dawson2 cluster at UCLA, Edison at NERSC, Mira at ALCF, and BlueWaters at NCSA.

Nonlinear Fluid Simulation Study of Stimulated Raman and Brillouin Scatterings in Shock Ignition

C. Ren, L. Hao[1], R. Yan[2], J. Li and W.-D. Liu
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[1]*Currently at Institute of Applied Physics and Computational Mathematics, Beijing, China*
[2]*Currently at Department of Modern Mechanics, University of Science and Technology, Hefei, China*

We developed a new nonlinear fluid laser-plasma-instability code *FLAME* using a multi-fluid plasma model combined with full electromagnetic wave equations. The completed one-dimensional (1D) version of *FLAME* was used to study laser-plasma instabilities in shock ignition. The simulations results showed that absolute Stimulated Raman Scattering (SRS) modes growing near the quarter-critical surface were saturated by Langmuir-wave Decay Instabilities (LDI) and pump depletion. The ion-acoustic waves from LDI acted as seeds of Stimulated Brillouin Scattering (SBS), which displayed a bursting pattern and caused strong pump depletion. Re-scattering of SRS at the 1/16th-critical surface was also observed in a high temperature case. These results largely agreed with corresponding Particle-in-Cell simulations.

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Vlasov-Fokker-Planck modeling of enhanced SRS growth in semi-collisional, laser-heated plasmas relevant to ICF

A.S. Joglekar[1,2], B. J. Winjum[2], W. B. Mori[2,3]

1 - Particle-in-Cell and Kinetic Simulation Center, University of California – Los Angeles

2 – Department of Electrical Engineering, University of California – Los Angeles

3 – Physics and Astronomy, University of California – Los Angeles

Much of the current understanding of stimulated Raman scattering (SRS) in the context of inertial confinement fusion (ICF) is based on collisionless plasma physics. The neglect of collisional effects is typically validated by comparing the relevant timescales between linear and non-linear electron plasma wave (EPW) oscillations, and electron-ion and electron-electron collisions. In ICF relevant laser-plasma interactions, $\omega_{pe} > \omega_B > \gamma_L \gg \nu_{ei} > \nu_{ee}$. However, even in these regimes, the effect of collisions on EPW and SRS is shown to be significant. Electron-electron collisions increase the threshold electric field required for the plasma to enact trapping oscillations. The presence of electron-ion collisions heats the plasma by the inverse-bremsstrahlung mechanism, and results in a modification of the distribution function [2] and reduction in Landau damping rates [3]. In a laser speckle where the intensity may be 5x the average intensity of a NIF beam, self-consistent collisional-kinetic modeling shows that the damping rates are reduced, and growth rates are significantly enhanced in comparison to those in a purely collisionless system.

References:

[1] – Langdon, A. B. (1980). *Physical Review Letters*, *44*(9)

[2] – Afeyan, B. B. et. al (1998). *Physical Review Letters*, *80*(11)

Investigation of stimulated Raman scattering driven by two or multiple, picosecond laser pulses

C. ROUSSEAUX[1], S. D. BATON[2], K. GLIZE[1,3], L. LANCIA[2,4]
D. BÉNISTI[1], L. GREMILLET[1]

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In this presentation, we consider, both experimentally and numerically, backward stimulated Raman scattering (SRS) excited collectively by two short laser pulses [1] [2]. The experiments have been carried out at the LULI facility using two co-propagating 1-µm wavelength, 1.5-ps duration laser pulses focused in a preformed underdense He plasma. A particular emphasis is laid on the configuration where the pulses are focused side-by-side, with a lateral distance of 80–90 µm, but not simultaneously.

It is experimentally demonstrated that a weak-intensity speckle, ineffective when fired alone in a preformed plasma, yields a significant SRS-induced reflectivity if launched a few picoseconds after a strong one. The data have been obtained by using both highly space-time resolved Thomson diagnostics and space-resolved SRS reflectivity measurements. By choosing either parallel or orthogonal polarizations for the two laser pulses, our experiments shed light on the role of either electrostatic or electromagnetic seeding in enhancing SRS from weak-intensity speckles.

A major finding is that seeding operates over unexpectedly long times (15–20 ps under our experimental conditions). Similar results are obtained in lower-density plasmas, or when the weak pulse is smoothed by a random phase plate, thus leading to multiple speckle interaction, while the strong pulse is focused within the speckle pattern. The data are discussed with the help of particle-in-cell numerical simulations, which confirm the destabilizing effect of the strong pulse over the weak one after a short transient time. The enhancement of the electron density fluctuations, induced by the non-Maxwellian electrons generated by the strong laser pulse driving SRS, is thought to play an important role in destabilizing the weak pulse interaction.

References

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Phys. Plasmas **24**, 032708 (2017).

[2] C. Rousseaux, K. Glize, S. D. Baton, L. Lancia, D. Bénisti, L. Gremillet
Phys. Rev. Lett. **117**, 015002 (2016).

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Planar Laser–Plasma Interaction Experiments at Direct-Drive Ignition-Relevant Scale Lengths at the National Ignition Facility

M. J. ROSENBERG [1], A. A. SOLODOV [1], W. SEKA [1], J. F. MYATT [1], P. MICHEL [2], S. P. REGAN [1], M. HOHENBERGER [2], R. EPSTEIN [1], A. V. MAXIMOV [1], T. J. B. COLLINS [1], V. N. GONCHAROV [1], R. W. SHORT [1], D. TURNBULL [1], R. K. FOLLETT [1], D. H. FROULA [1], P. B. RADHA [1], T. CHAPMAN [2], J. D. MOODY [2], L. MASSE [2], C. S. GOYON [2], J. D. MOODY [2], J. W. BATES [3], and A. J. SCHMITT [3]

[1] *Laboratory for Laser Energetics, University of Rochester*

[2] *Lawrence Livermore National Laboratory*

[3] *Naval Research Laboratory*

The first experiments at the National Ignition Facility to probe laser–plasma interactions and hot-electron production at scale lengths relevant to direct-drive ignition are reported. The irradiation on one side of planar foils generated a plasma at the quarter-critical surface with predicted density scale lengths of L_n ~ 500 to 700 μm, electron temperatures of T_e ~ 4 to 5 keV, and overlapped laser intensities of I ~ 6 to 15 × 10^{14} W/cm^2. Only a sharp red-shifted feature is observed around $\omega/2$, suggesting that stimulated Raman scattering (SRS) dominates hot-electron production, unlike in shorter-scale-length plasmas on OMEGA that are dominated by two-plasmon decay (TPD). This difference in regime is explained based on SRS and TPD thresholds. Optical measurements show evidence of significant SRS sidescattering. For CH targets, the fraction of laser energy converted to hot electrons increases from ~0.5% to ~2.3% as the laser intensity increases from ~6 to 15 × 10^{14} W/cm^2, while the hot-electron temperature is nearly constant around 40 to 50 keV. Initial experiments using Si targets have demonstrated a reduction in SRS and in hot electrons relative to a CH target. These results have implications for hot-electron preheat mitigation strategies for direct-drive ignition.

This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944, the University of Rochester, and the New York State Energy Research and Development Authority. The support of DOE does not constitute an endorsement by DOE of the views expressed in this article.

Measurements and modeling of Raman side-scatter in ICF experiments*

P. Michel[1], M. J. Rosenberg[2], T. Chapman[1], R. W. Short[2], W. Seka[2], A. Solodov[2], C. Goyon[1], M. Hohenberger[1], J. D. Moody[1], S. P. Regan[2] and J. F. Myatt[2]

1) Lawrence Livermore National Laboratory, Livermore, CA 94551
2) Laboratory for Laser Energetics, University of Rochester, 250 East River Road, Rochester, New York 14623-1299, USA

Raman side-scatter, whereby the Raman scattered light is resonant at its turning point in a density gradient, was identified experimentally in planar-target experiments at the National Ignition Facility (NIF) in conditions relevant to the direct-drive scheme of inertial confinement fusion (ICF). This process was found to be one of the principal sources of supra-thermal electrons in such conditions, which can preheat the target and reduce its compressibility. We have developed a new semi-analytical model of the instability, which describes both its convective and absolute aspects; we derived quantitative estimates of the amplification region in typical ICF regimes, which highlights the need for sufficiently large laser spots to allow the instability to develop. Full-scale simulations of these experiments using the laser-plasma interaction code ``pF3d" show SRS side-scatter largely dominating over back-scatter, and reproduce the essential features observed in the experiments and derived in the theory; we provide extrapolations to the case of spherical geometries relevant to direct-drive and discuss implications for indirect-drive ICF experiments.

* This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344, and was supported by the LLNL-LDRD Program under Project No. 42074.

Observation of Stimulated Raman Scattering and Two-Plasmon–Decay Instabilities on OMEGA and the National Ignition Facility

W. SEKA [1], J. F. MYATT [1], P. MICHEL [2], M. J. ROSENBERG [1], A. A. SOLODOV [1], T. CHAPMAN [2], S. P. REGAN [1], R. W. SHORT [1], D. T. MICHEL [1], and R. K. FOLLETT [1]

[1]*Laboratory for Laser Energetics, University of Rochester*

[2]*Lawrence Livermore National Laboratory*

Stimulated Raman scattering (SRS) and two-plasmon decay (TPD) are observed in direct-drive experiments on OMAGA and the National Ignition Facility (NIF) to varying degrees depending on irradiation and plasma parameters (10^{14} W/cm^2 to 10^{15} W/cm^2, T_e ~ 2 to 5 keV, L_n ~ 100 to 600 μm) and angle of observation. In general, both TPD and SRS may occur at the same time and distinguishing between the corresponding experimental signatures is nontrivial.

A long-standing mystery for convective SRS observations has been the "Raman gap" close to $2\lambda_0$ between the signals caused by the absolute SRS instability and the onset of the convective SRS. Standard SRS theory in linear density gradients predicts no such gap. SRS observations on OMEGA and the NIF and recent pF3D simulations indicate that this gap is most likely caused by a combination of three effects: (1) convective SRS preferentially occurs tangential to the isodensity surfaces below $n_c/4$, (2) refraction of this sidescattered light varies strongly with density and most of it is likely to miss the SRS detector, and (3) absorption near $n_c/4$ is very strong but decreases rapidly toward lower densities. In many cases, the SRS detector is oriented to detect "backscattering" but the light reaching it may be caused by side scattering that was refracted into the backscatter direction.

We will present experimental SRS and TPD spectra from OMEGA and the NIF that illustrate the various effects that can lead to the frequently observed "Raman gap." We will also present a few cases where this gap is nearly absent. The effects leading to the "Raman gap" also make it difficult to assess the total amount of SRS losses in these experiments.

This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944, the University of Rochester, and the New York State Energy Research and Development Authority. The support of DOE does not constitute an endorsement by DOE of the views expressed in this article.

Absolute Stimulated Raman Scattering in Direct-Drive Irradiation Geometries

R. W. SHORT, A. V. MAXIMOV, and W. SEKA
Laboratory for Laser Energetics, University of Rochester

As the plasmas involved in direct-drive laser-fusion experiments increase in scale length and temperature, the relative importance of absolute stimulated Raman scattering (SRS) relative to two-plasmon decay is expected to increase, owing to the stronger dependence on scale length and weaker dependence on temperature of the former.[1] In this talk, a formalism is presented to investigate absolute SRS in the context of direct-drive irradiation, comprising multiple beams at varying angles of incidence and polarization. Representative examples will be presented to illustrate the behavior of absolute SRS under these conditions, with emphasis on sidescatter at wavelengths below the half-harmonic of the laser

This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944, the University of Rochester, and the New York State Energy Research and Development Authority.

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[1] C. S. Liu, M. N. Rosenbluth, and R. B. White, Phys. Fluids **17**, 1211 (1974).

❖ Morning Session ❖

Pacific Room

9:00AM	Cross-Beam Energy Transfer
11:00AM	Kinetics Effects II

❖ Evening Session ❖

7:00 PM	Review Talk H.G. Rinderknecht, LLNL

❖ Poster Session ❖

Pacific Room

8:00 PM	Poster Session
10:00 PM	Adjourn

❖

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Thursday, June 15, 2017 Pacific Room

	8:00 AM - 9:00 AM	Breakfast
Oral Session:	*Cross-Beam Energy Transfer*	*Chair: W. Seka, Laboratory for Laser Energetics*
ThI-1	9:00 AM	Refractive Index Seen by a Probe Beam Interacting with a Laser-Plasma System *Presented by D. P. Turnbull, Laboratory for Laser Energetics*
ThO-1	9:30 AM	Interplay between Crossed-Beam Energy Transfer and Beam Propagation in Plasmas *Presented by C. Neuville, LULI-CNRS, Ecole Polytechnique*
ThO-2	9:50 AM	Three-Dimensional Modeling of Cross-Beam Energy Transfer and Its Mitigation in OMEGA Implosions *Presented by D. H. Edgell, Laboratory for Laser Energetics*
ThO-3	10:10 AM	High Laser Beam Energy and Fluence Produced with a Plasma Beam Combiner at NIF *Presented by R. K. Kirkwood, Lawrence Livermore National Laboratory*
	10:30 AM	Break
Oral Session:	*Kinetic Effects II*	*Chair: G. Kagan, Los Alamos National Laboratory*
ThI-2	11:00 AM	Effects of dimensionality and laser polarization on kinetic simulations of laser-ion acceleration in the transparency regime *Presented by D. J. Stark, Los Alamos National Laboratory*
ThO-4	11:30 AM	Collisional De-trapping of electrons in an Electron Plasma Wave *Presented by R. L. Berger, Lawrence Livermore National Laboratory*
ThO-5	11:50 AM	Hot-Electron Generation at Direct-Drive Ignition-Relevant Plasma Conditions at the National Ignition Facility *Presented by A. A. Solodov, Laboratory for Laser Energetics*
	12:10 PM	Pick up box lunches

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Thursday, June 15, 2017 Pacific Room

Oral Session: *Review Talk* 7:00 PM

Chair: F. Tsung, University of California, Los Angeles
The Kinetic Physics in ICF Workshop: Findings and Paths Forward
Presented by H. G. Rinderknecht, Lawrence Livermore National Laboratory

Poster Session 8:00 PM - 10:00 PM

ThP-1
Mitigation of cross-beam energy transfer in inertial-confinement-fusion plasmas with enhanced laser bandwidth
Presented by J. Bates, US Naval Research Laboratory

ThP-2
Full-Wave and Ray-Based Models of Cross-Beam Energy Transfer
Presented by R. K. Follett, Laboratory for Laser Energetics

ThP-3
3D Laser Propagation and Intensity Field Estimation in Plasmas, Model and Applications
Presented by A. Colaitis, Lawrence Livermore National Laboratory

ThP-4
Stochastic acceleration of electrons from multiple uncorrelated plasma waves
Presented by D. D. Gee, University of California, Berkeley

ThP-5
Multigrid Charge Conservation in Particle-in-Cell Simulations *Presented by K. G. Miller, University of California, Los Angeles*

ThP-6
Neutron Generation from Laser-Accelerated Ion Beams: Use of Alternative Deuteron-Rich Target Materials to Enhance Neutron Yield and Control Neutron Spectra
Presented by B. J. Albright, Los Alamos National Laboratory

ThP-7
Exploration of LPI Mitigation Strategies
Presented by J. Weaver, US Naval Research Laboratory

ThP-8
Parametric Instabilities in Inhomogeneous Plasmas: An Old Topic Revisited and Quantified – Consequences for LPI
Presented by M. Casanova, Commissariat à l'Energie Atomique

ThP-9
Controlling Laser-Plasma Instabilities Near the Quarter Critical Layer Using Temporal Bandwidth
Presented by F. S. Tsung, University of California, Los Angeles

ThP-10
Transforming the Idler to Seed Raman Amplification
Presented by S. Bucht, Laboratory for Laser Energetics

ThP-11
Toward high fluence, high energy x-ray sources via control and optimization of plasma instabilities
Presented by P. L. Poole, Lawrence Livermore National Laboratory

Refractive Index Seen by a Probe Beam Interacting with a Laser-Plasma System

D. TURNBULL [1], P. MICHEL [2], C. GOYON [2], T. CHAPMAN [2], G. E. KEMP [2], B. B. POLLOCK [2], D. MARISCAL [2], L. DIVOL [2], J. S. ROSS [2], S. PATANKAR [2], J. D. MOODY [2], D. H. EDGELL [1], R. K. FOLLETT [1], J. F. MYATT [1], D. H. FROULA [1], and E. M. CAMPBELL [1]
[1]*Laboratory for Laser Energetics, University of Rochester, USA*
[2]*Lawrence Livermore National Laboratory, USA*

We report the first complete set of measurements of a laser-plasma optical system's refractive index, as seen by an independent probe laser beam, as a function of the relative wavelength shift between the two laser beams. Both the imaginary and real refractive index components are found to be in good agreement with linear theory using measured plasma parameters; the former is in contrast to previous work and has implications for cross-beam energy transfer (CBET) in inertial confinement fusion experiments, and the latter is measured for the first time. The data include the first demonstration of a laser-plasma polarizer with 85% to 87% extinction for the particular laser and plasma parameters used in this experiment, complementing the existing suite of high-power, tunable, and ultrafast plasma-based photonic devices.[1] An upcoming experiment will utilize the rapid variation in the real refractive index near the peak of the ion-acoustic wave to demonstrate slow and fast light in plasma. In addition, the introduction of a wavelength-tunable beam at the Omega Laser Facility—plans for which are underway—will facilitate additional CBET investigations, including a demonstration of CBET mitigation via wavelength detuning on an integrated spherical implosion.

This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944, the University of Rochester, and the New York State Energy Research and Development Authority. The support of DOE does not constitute an endorsement by DOE of the views expressed in this article.

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[1] D. Turnbull, C. Goyon, G. E. Kemp, B. B. Pollock, D. Mariscal, L. Divol, J. S. Ross, S. Patankar, J. D. Moody, and P. Michel, "Refractive Index Seen by a Probe Beam Interacting with a Laser-Plasma System," Phys. Rev. Lett. **118** (1), 015001 (2017).

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Interplay between Crossed-Beam Energy Transfer and Beam Propagation in Plasmas

C. Neuville, K. Glize[†], C. Baccou[†], P. Loiseau, S. Hüller[‡], P.-E. Masson-Laborde, A. Debayle, M. Casanova, C. Labaune[†] and S. Depierreux
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The interaction with multiple beams in plasmas naturally occurs in the context of laser fusion. When two beams are crossing in a plasma, the density perturbation driven by their ponderomotive beating can scatter energy from one of the beam into the direction of the other by induced stimulated Brillouin scattering, also called crossed-beam energy transfer (CBET). For superimposed intensity from 10^{14} to 10^{16} W/cm^2, this mechanism is ruled by the plasma ion acoustic response. It can redistribute the energy between incident and refracted beams in direct-drive experiments or between co-propagating beams in indirect-drive experiments.

An experimental platform was designed on the LULI2000 facility, at Ecole Polytechnique (Palaiseau, France), to study CBET. A first kilojoule nanosecond beam, later called the heating beam, preformed a plasma by irradiating a CH foil. A second nanosecond beam, later called the nanosecond beam, and a picosecond beam were crossed in the preformed plasma after or before the end of the heating beam in order to study CBET in conditions of crossing two or three beams. A high resolution 2D spatial imaging diagnostic was used to measure the focal spot of the picosecond beam after the crossing region and to quantify energy transfer from the nanosecond beam to the picosecond beam [1]. Additionally, time-resolved measurements of the transmitted power in the direction of the nanosecond beam were performed. They enabled us to observe and characterize the energy transfer from the heating beam to the nanosecond beam.

We will present these experiments and results from the two-beams and three-beams configurations. In the two-beams experiments, the CBET coupling coefficient highly depended on the intensity of the picosecond beam. It could be the proof of an interplay between CBET, self-focusing and plasma-induced smoothing of the picosecond beam. In the three-beams experiments, we observed the inhibition of the energy transfer from the heating beam to the nanosecond beam during hundreds of picoseconds because of the propagation of the picosecond beam (12ps duration) in the crossing volume. This inhibition could be induced by the production of long-wavelength hydrodynamical fluctuations in the crossing volume because of the propagation of the picosecond beam. In both cases, CBET appears to be highly affected by the propagation of the beams in the plasmas.

References

[1] C. Neuville *et al.*, Phys. Rev. Lett. **117**, 145001 (2016)

Three Dimensional Modeling of Cross-Beam Energy Transfer and Its Mitigation in OMEGA Implosions

D. H. EDGELL, R. K. FOLLETT, I. V. IGUMENSHCHEV, J. F. MYATT, J. G. SHAW, and D. H. FROULA
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The effects of frequency detuning laser beams in direct-drive symmetric implosions are calculated with a 3-D cross-beam energy transfer (CBET) model. The model shows that interactions between beams with relative angles between 45° and 90° are most significant for CBET in OMEGA direct-drive implosions. There is no net exchange in power between beams but there is significant redistribution of power from the ingoing central portion of the beam profile to the outgoing edge as it is exiting the plasma, reducing the total absorbed power. Redistribution of laser power because of CBET can increase the root-mean-square (rms) absorption nonuniformity by an order of magnitude. CBET mitigation by shifting relative wavelengths of three groups of laser beams fed by each of the different beamlines is modeled. At an on-target wavelength shift of $\Delta\lambda \sim 10$ Å, the total laser absorption was maximized, and the rms absorption nonuniformity was near minimum. To completely decouple the three groups of beams from each other requires wavelength shifts $\Delta\lambda > 30$ Å.

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High Laser Beam Energy and Fluence Produced with a Plasma Beam Combiner at NIF

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The seeded SBS process that is known to effectively amplify beams in ignition targets [1] has recently been used to design and test a target to combine the power and energy of many beams of the NIF facility into a single beam by intersecting them in a plasma produced by a gas filled target [2]. The demand for high-power beams for a variety of applications at NIF makes a demonstration of this process attractive. We will describe experiments using a gas-filled balloon heated by 10 quads of beams, and pumped by up to two frequency-tuned quads to resonantly amplify a single beam by SBS (CBET), and discuss how the technique can be expanded to include up 5 resonant quads at NIF. The amplified beam transmitted energy is indicated in the experiments by analysis of x-ray images of the spots produced by the transmitted seed beam and by a non-interacting quad of beams when they both terminate on a foil that is external to the plasma [3]. Experiments have demonstrated that the transmitted seed beam energy increases with the number of pumping quads as was demonstrated in experiments in shorter scale plasmas where linear CBET gains [4] were validated in both single pump and multi-pump experiments [5,6]. With two pump quads incident on the plasma, a the single seed beam with 0.75 kJ incident in a 1ns duration pulse is amplified to 4 +- 1 kJ and delivered to the foil. This is substantially higher than the energy in any of the incident beams during the same time period and represents a substantial fraction of the 8.8 kJ of resonant pump energy incident in that period. Though lower levels of amplification and lower single beam energies have been produced in ignition targets [1] the energy in those beams is absorbed by inverse Bremsstrahlung or backscattered within the target. These observations are the first demonstration that multi-beam SBS amplification in a plasma can produce a beam that emerges from the plasma brighter than any of the incident beams, and that can be deposited on a secondary target, which is a technology that is expected advance a wide range of HEDP applications. Further PF3D simulations show consistency with observed energies and a distortion in the shape of the amplified beam spot when the plasma is asymmetrically pumped with a single quad of beams and the effects of pump depletion, speckle distributions and the 3D beam profile and crossing geometry are included [7]. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

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Effects of dimensionality and laser polarization on kinetic simulations of laser-ion acceleration in the transparency regime*

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The often cost-prohibitive nature of three-dimensional (3D) kinetic simulations of laser-plasma interactions has resulted in a heavy dependence by the field on two-dimensional (2D) simulations to extract the physics and quantitative predictions from a system. In the context of laser-ion acceleration in the transparency regime, we demonstrate with VPIC particle-in-cell simulations [1] that the 2D-S and 2D-P (laser polarization in and out of the simulation plane, respectively) capture different physics that appears in 3D simulations. We observe that while 2D-S simulations exhibit a much more isotropic electron distribution in momentum space (similar to 3D), those in 2D-P show dramatically greater heating in the simulation plane so that the momentum distribution is virtually two-dimensional. As a result, target expansion timescales, electric field strengths, and density thresholds for the onset of relativistic transparency differ dramatically between the two simulation classes [2]. By performing ion trajectory and spectral analysis, we isolate the fields and modes responsible for acceleration and characterize the acceleration regimes in time and space. The artificial longitudinal electron heating in 2D-P exaggerates the effectiveness of target-normal sheath acceleration (TNSA) into its dominant acceleration mechanism throughout the laser-plasma interaction, whereas 2D-S and 3D both have sizable populations accelerated preferentially during transparency [3] to higher energies than those of TNSA.

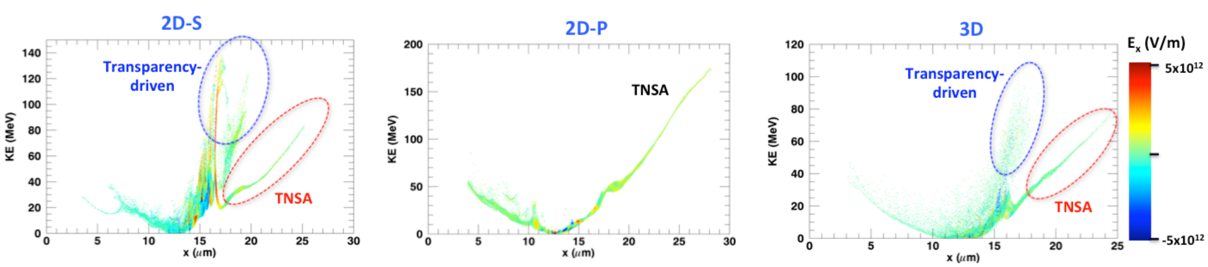

Figure 1: Scatter plot (from 2D-S, 2D-P, and 3D simulations of 10 n_{cr} carbon target irradiation) of the tracer ions at 580 fs between kinetic energy and longitudinal axis *x*, color-coded by the E_x field experienced by the particle at the time [2].

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Collisional De-trapping of electrons in an Electron Plasma Wave

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Kinetic simulations of the effects of electron-ion pitch-angle and electron-electron scattering on finite-amplitude Electron Plasma Waves (EPWs) are considered.
The simulations show that, as the collision rate increases compared to the plasma frequency, collisional de-trapping of electrons in initially large-amplitude EPWs or driven EPW waves leads to a restoration of linear damping rates (Landau + collisional) of the wave.
The magnitude of the collision rate required to prevent trapping agrees well with simple estimates.[1] We also compare our results in 2V and 3V to theory and simulations using approximate 1V collision operators.[2],[3]
Both the 2D+2V LOKI[4] and the 1D+3V SAPRISTI Vlasov codes are used.

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Hot-Electron Generation at Direct-Drive Ignition-Relevant Plasma Conditions at the National Ignition Facility

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Laser–plasma interaction instabilities, such as two-plasmon decay (TPD) and stimulated Raman scattering (SRS), can be detrimental for direct-drive inertial confinement fusion because of target preheat by generated high-energy electrons. The radiation–hydrodynamics code *DRACO* has been used to design planar-target experiments that generate plasma and interaction conditions relevant to direct-drive–ignition designs (I_L ~ 10^{15} W/cm^2, $T_e > 3$ keV, and density gradient scale lengths of L_n ~ 600 μm). The hot-electron properties were inferred by comparing the experimentally observed hard x-ray emission spectra and Monte Carlo simulations. The hot-electron temperature of ~45 to 60 keV and the fraction of laser energy converted to hot electrons of ~0.5 to 3% were inferred when the laser intensity at the quarter-critical surface increased from ~6 to 15 × 10^{14} W/cm^2. Planar experiments at the National Ignition Facility were dominated by SRS, as confirmed by the scattered-light spectra measurements, while the previous OMEGA experiments were dominated by TPD. The measured SRS energy was found to be sufficient to explain the observed total energy in hot electrons. The use of Si ablators was found to reduce the hot-electron temperature by ~15 keV and the energy of hot electrons above ~50 keV (which are relevant to preheat) by ~35%, compared to the relevant CH target shots. Implications for ignition-scale direct-drive experiments and hot-electron preheat mitigation using mid-*Z* ablators will be discussed.

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The Kinetic Physics in ICF Workshop: Findings and Paths Forward

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The Kinetic Physics in ICF Workshop, hosted at Lawrence Livermore National Laboratory on April 5—7, 2016, brought together researchers from around the world to address the potential impact of kinetic physics on indirect-drive ICF. [1] Thirty-eight talks and topical discussion sessions presented and weighed the evidence for non-fluid phenomena in ICF, summarized the status of analytical and numerical techniques to study these phenomena, and mapped out an experimental and computational path forward to quantitatively assess the role of kinetic phenomena in ICF pertaining to the NIF database. Systematic anomalies in the NIF implosion dataset were identified in which kinetic physics may play a role, including inferred missing energy in the hohlraum, drive asymmetry in near-vacuum hohlraums, low areal density and high burn-averaged ion temperatures ($\langle T_i \rangle$) compared with mainline simulations, and low ratios of the DD-neutron and DT-neutron yields and inferred $\langle T_i \rangle$. Several components of ICF implosions were identified that are likely to be influenced or dominated by kinetic physics: laser-plasma interactions in the LEH and hohlraum interior; the hohlraum wall blowoff, blowoff/gas and blowoff/ablator interfaces; the ablator and ablator/ice interface; and the DT fuel present conditions in which higher-fidelity physics can significantly affect the dynamics. This review presentation will summarize the assembled experimental data and simulation results to date, which indicate that the effects of long mean-free-path plasma phenomena and self-generated electromagnetic fields may have a significant impact in ICF targets. The proposed simulation and experimental effort to definitively quantify the importance of these effects at ignition-relevant conditions will be discussed, including progress in the year since the workshop and priorities for ongoing study.

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Mitigation of cross-beam energy transfer in inertial-confinement-fusion plasmas with enhanced laser bandwidth*

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Cross-beam energy transfer (CBET) is a laser plasma instability (LPI) in which two overlapping laser beams exchange energy by means of a resonantly-excited ion-acoustic wave in an expanding supersonic plasma [1]. CBET can cause a significant amount of the incident laser energy to be misdirected in direct-drive inertial-confinement-fusion (ICF) implosions, thereby reducing both the maximum ablation pressure achieved and the overall symmetry of the implosion [2,3]. Last year, a working group at the Laboratory for Laser Energetics (LLE) and the U.S. Naval Research Laboratory was formed to study strategies for mitigating CBET using LLE's code LPSE-CBET. One such strategy for mitigating CBET may be to increase the bandwidth of the laser light, thereby disrupting the coherent wave-wave interactions that resonantly excite this parametric process. In this presentation, we report on results of recent two-dimensional LPSE-CBET simulations in planar geometry that demonstrate a significant reduction in CBET gain for laser bandwidths between 2 and 5 THz under realistic plasma conditions. We also discuss some preliminary results in the modeling of stimulated rotational Raman scattering (SRRS). The use of SRRS techniques may provide a straightforward means of enhancing the bandwidth of existing ICF lasers, which would likely have beneficial LPI effects in both direct and indirect drive approaches.

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Full-Wave and Ray-Based Models of Cross-Beam Energy Transfer

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Ray-based models of cross-beam energy transfer (CBET) are used in radiation–hydrodynamics codes to calculate laser-energy deposition. The accuracy of ray-based CBET models is limited by the assumption of a local plane-wave solution and by the treatment of the CBET interaction near caustics where the eikonal solution for the electromagnetic fields is singular. A 3-D wave-based solver (*LPSE* CBET) is used to study the nonlinear interaction between overlapping laser beams in underdense plasma. Ray-based models show good agreement with the full-wave calculation in simple geometries where there are no caustics. In full-scale 2-D calculations using plasma conditions relevant to direct-drive inertial confinement fusion, there are significant differences between the two models. The results suggest that the simple limiters placed on the eikonal field amplitudes at the caustics that are typically used in radiation–hydrodynamics simulations are not sufficient to reproduce the results of the full-wave calculation.

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3D Laser Propagation and Intensity Field Estimation in Plasmas, Model and Applications*

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Non-linear Laser-Plasma Interaction (LPI) processes are prominent in both the direct and indirect drive approaches to ICF, redistributing laser energy in the plasma and eventually accelerating supra-thermal electron populations. Modeling these processes at fluid scales (mm, ns) and for many interacting beams remains a challenge, due to the necessity to describe both the microscopic and macroscopic scales. At fluid scales, the laser propagation is often described by a Geometrical Optics (GO) approach, which does not carry information on the field amplitude [1,2]. Standard GO-based intensity field reconstruction relies on using a high number of rays relative to the mesh discretization to estimate the field from collisional absorption. This CPU-intensive approach is ill-suited to problems where the ray density decreases (e.g. when the beam sprays) [2]. Furthermore, it is not able to reproduce the intensity statistics of phaseplate-smoothed laser beams.

We propose an alternative field estimation method intended to describe non-linear LPIs more naturally. First, the incident wavefield refraction is sampled using Geometrical Optics. Then, the intensity field is estimated inside the convex hull of the sampling points by reconstructing the electromagnetic energy density using optimal estimators and interpolators based on a Delaunay partition of space [3,4]. This unbiased estimator being naturally sensitive to initial noise, we relax the local sampling point density using penalized centroidal Voronoi tessellation. The penalization factor is chosen by comparison with Paraxial simulations of laser propagation using the NIF phaseplate data, yielding a favorable comparison in terms of intensity statistics and envelope profile. It is also found to be significantly faster than the standard absorption-based reconstruction techniques. We present two applications of the model to NIF experiments: a study of the glint spectra in low gas-fill holhraums and a study of a beam amplification experiment that uses Cross-Beam Energy Transfer.

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Stochastic acceleration of electrons from multiple uncorrelated plasma waves*

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One-dimensional theory puts a strict limit on the maximum energy attainable by an electron trapped and accelerated by an electron plasma wave (EPW). However, experimental measurements of hot electron distributions accelerated by stimulated Raman scattering (SRS) in ICF experiments typically show a thermal distribution with temperatures of the order of the kinetic energy of the resonant EPW's ($T_{hot} \sim mv_p^2$, where v_p is the phase velocity of the EPW's driven by SRS) and no clear cutoff at high energies. Simulations are being developed to study electron dynamics in multiple EPW's created by the SRS of incoherent laser speckles with parameters typical of the large laser (~mm-size) spots in NIF pulses. In particular, in this project we investigate the conjecture that multiple incoherent EPW's may lead to stochastic electron acceleration and produce electron distributions similar to those observed in NIF experiments.

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Multigrid Charge Conservation in Particle-in-Cell Simulations

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Particle-in-cell (PIC) plasma simulations numerically solve Maxwell's equations in order to calculate the trajectories of particles as they interact via fields calculated on a grid. Some available solvers are not rigorously charge conserving, e.g., a solver that mitigates the numerical Cerenkov instability through the use of a higher order stencil when a plasma drifts near the speed of light. Over time, these solvers develop a discrepancy in Gauss' law. A new scheme to enforce Gauss' law using a multigrid approach for an arbitrary finite difference operator has been implemented for fast convergence. The increased speed and parallelizability of the multigrid approach compared to traditional point-Jacobi iteration may allow for efficient charge conservation in PIC simulations for a variety of solvers and geometries. We will describe the approach and present simulation results using the new solver.

We will also discuss this work within the context of the Particle-in-Cell and Kinetic Simulation Software Center (PICKSC) at UCLA. PICKSC is an NSF-funded program which aims to support an international community of PIC and plasma kinetic software developers, users, and educators, and to increase the use of PIC software for accelerating the rate of scientific discovery. PICKSC is making many of its codes available, including electrostatic, Darwin (non-radiative electromagnetic), and fully electromagnetic and relativistic PIC codes which implement a variety of spectral (FFT-based) and hybrid (FFT and finite-difference) solvers.

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- Prefer Poster

Neutron Generation from Laser-Accelerated Ion Beams: Use of Alternative Deuteron-Rich Target Materials to Enhance Neutron Yield and Control Neutron Spectra

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Kinetic modeling of laser-ion beam generation from the “break-out afterburner” (BOA) has been performed for nano-foils from several different deuteron-rich solid-density target materials. Monte Carlo modeling of the transport of these beams in a beryllium converter shows that some alternative target materials may lead to as much as a fourfold increase in neutron yield over the present state of the art [1]. Analysis of VPIC [2] kinetic plasma simulation spectra and novel particle-tracking diagnostics show that this may be accomplished in two ways: through increasing the mass ratio of deuterons relative to other species (e.g., through use of materials such as cryogenic deuterated methane or deuterated ammonia); and, through choosing non-deuterium target components such that their charge-to-mass ratios are smaller (slightly) than that of deuterons, leading to species-separation dynamics during the BOA that produces deuteron beams of higher average energy [3]. This latter process both boosts deuteron yield through longer stopping ranges and higher deuteron-breakup nuclear cross sections and allows control of the hardness of the neutron spectra, of interest for enhancing penetrability in shielded material in active neutron interrogation settings.

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Exploration of LPI Mitigation Strategies*

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The laser fusion program at the Naval Research Laboratory (NRL) has a multifaceted experimental program exploring several approaches for reducing laser plasma instabilities (LPI). This effort aims to exploit and extend features of excimer lasers with induced spatial incoherence (ISI) to mitigate crossed beam energy transfer (CBET), two plasmon-decay instability, and stimulated Raman scattering at laser intensities currently envisioned for the compression stage of implosions. A significant effort is being dedicated to understanding the role of the laser spectrum in the growth of LPI. The output spectrum of the Nike laser at NRL can be readily manipulated by etalons installed at the output of the initial oscillator. Target experiments are being planned to examine the effects of wavelength shifting and bandwidth changes on CBET in low density (a few mg/cm^3) CH foam targets. Experiments are also being planned to explore the application of stimulated rotational Raman scattering (SRRS) in the propagation bay of the Nike laser as a means to expand the bandwidth beyond the 2-3 THz of the current system. These new experiments build upon existing SRRS measurements that demonstrated a ~2X reduction in laser coherence time with only a modest effect on the beam quality. There is also an initiative at NRL to demonstrate a high energy excimer laser that uses an argon-fluorine medium in place of the krypton-fluorine currently in use. This change shifts the peak wavelength from 248 nm to 193 nm and may increase the laser bandwidth as well. Hydrodynamic simulations of implosions driven at 193 nm demonstrate ignition at lower laser energies than for comparable designs using 351 nm light. These simulations show a further advantage that the shorter wavelength drive does not exceed the single-beam intensity threshold for the two-plasmon decay instability while comparable designs with 351 nm light can be well above threshold.

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Parametric Instabilities in Inhomogeneous Plasmas: An Old Topic Revisited and Quantified – Consequences for LPI

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The question of parametric instabilities in an inhomogeneous plasma remains an important issue, because the linear behavior of stimulated Raman scattering (SRS), stimulated Brillouin scattering (SBS) and, more generally, laser-plasma interactions (LPI), depends dramatically on the details of the inhomogeneity. To go beyond the amplificator model (LIP, PIRANAH, etc.), which is simple enough to appeal to the target designers, it is necessary to revisit and quantify old works based on coupled-mode equations. In order to get scaling laws and general tendencies, coupled-mode equations are much easier to deal with by comparison to more sophisticated LPI codes. They are well adapted for studying large-scale inhomogeneous plasmas. We consider here a decay process described by

$$\begin{cases} \left(\dfrac{\partial}{\partial t} + V_{g1}\dfrac{\partial}{\partial z}\right) a_1 = \gamma_0(z)\, a_2^* \\ \left(\dfrac{\partial}{\partial t} + V_{g2}\dfrac{\partial}{\partial z} + i\, V_{g2}\,\Delta k(z)\right) a_2 = \gamma_0(z)\, a_1^* \end{cases}$$

where the complex envelope amplitudes a_1 and a_2 respectively stand for the backscattered wave and the plasma wave (Langmuir wave or ion acoustic wave). Here, V_{g1}, V_{g2} are the z components of the group velocities, having either sign. The inhomogeneity is taken into account via (1) the wave-vector mismatch $\Delta k(z)$ and (2) the coupling constant $\gamma_0(z)$. We have performed numerical simulations of the above system in the case $V_{g1}V_{g2} < 0$ and for two kinds of inhomogeneity profiles :

1) $\Delta k(z) = (z - z_0)\left[1 \pm \left((z - z_0)/l_\varphi\right)^2\right] K'$

2) $\Delta k(z) = K'(z - z_0) \pm K_m \sin\left((z - z_0)/L_m\right)$

where K' is a density or velocity gradient, l_φ is a parameter which controls a cubic inhomogeneity, K_m and L_m are two parameters which characterize a sinusoidal modulation of the inhomogeneity. We revisit pioneering works[1-3], extending and quantifying their results. Consequences for laser-plasma interactions and their modeling will be discussed.

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Controlling Laser Plasma Instabilities Near the Quarter Critical Layer Using Temporal Bandwidth

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We are performing particle-in-cell simulations using the code OSIRIS to study the effects of laser plasma interactions in the presence of temporal bandwidth under conditions relevant to current and future experiments on the NIKE laser (which is capable of 2-3THz bandwidth). Our simulations show that, for sufficiently large bandwidth (where the inverse bandwidth is comparable with the linear growth time), the saturation level, and the distribution of hot electrons, can be effected by the addition of temporal bandwidths (which can be accomplished in experiments using beam smoothing techniques such as ISI). We will quantify these effects and investigate higher dimensional effects such as laser speckles using our new speckle package described elsewhere at this meeting.

- Work supported by DOE and NSF
- Prefer posters

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Transforming the Idler to Seed Raman Amplification

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A novel optical system has been designed to transform the idler produced in an optical parametric chirped-pulse–amplification (OPCPA) system into a useable high-power pulse for Raman amplification experiments. Analytic solutions and particle-in-cell simulations of Raman amplification indicate that high seed intensity is required for fast entry into the pump-depletion regime to achieve high energy-transfer efficiency. A high-intensity seed at the resonance condition can be obtained from the idler of an OPCPA system. The idler is an existing by-product created by all OPCPA systems and has similar bandwidth and energy to the signal. The nondegenerate configuration of the OPA can produce an idler at a unique wavelength for a high-power laser system. With a proper stretcher and compressor it provides a high-intensity laser pulse. The complex phase reversal of the signal to idler in an OPCPA requires a grism stretcher when using a standard grating compressor. An optical design will be presented for a grism stretcher, angular dispersion compensator, and grating compressor, which together will produce a 200-fs seed pulse at 1170 nm with 100 mJ of energy.

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Toward high fluence, high energy x-ray sources via control and optimization of plasma instabilities

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X-ray source development on high power laser facilities aims to mimic high fluence x-ray environments for national security and materials testing applications[1]. While current efforts can produce high energies of x-rays (~10 kJ) with photon energy near 20 keV from k-shell emission of Mo and Ag, extending these methods to higher Z materials will come with a sharp reduction in x-ray conversion efficiency. Alternatively, pulsed power sources excel at generating large numbers of x-rays above several hundred MeV, but this leaves a critical gap in capability for 30 – 100 keV x-rays.

As such, efforts are underway to produce a continuum source of high energy (30 – 100 keV) x-rays at high fluence levels via bremsstrahlung radiation from electrons that are accelerated through plasma instabilities such as Stimulated Raman Scattering and Two Plasmon Decay. Working to enhance these instabilities is a marked departure from conventional HED applications where they typically result in unwanted laser-plasma interaction asymmetries. However, there is significant knowledge gathered to reduce these effects that can instead be applied here to their enhancement, and conversely development of plasma instability control will in turn aid in their mitigation.

We will present modeling efforts designing plasma conditions to this novel end of enhancing plasma instability growth on Omega and NIF, as well as initial results from Omega shots with the same goal.

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❖ Morning Session ❖
Pacific Room

9:00 AM	Implosions II
10:30 AM	Implosions III & LPI
11:10 AM	Adjourn

❖

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Friday, June 16, 2017 Pacific Room

	8:00 AM - 9:00 AM	Breakfast
Oral Session:	*Implosions II*	*Chair: D. J. Strozzi, Lawrence Livermore National Laboratory*
FrI-1	9:00 AM	Ignition and pusher adiabat *Presented by B. Cheng, Los Alamos National Laboratory*
FrO-1	9:30 AM	Hybrid Drive on the National Ignition Facility *Presented by R. Nora, Lawrence Livermore National Laboratory*
FrO-2	9:50 AM	The latest on High-Density Carbon Capsule implosions at the National Ignition Facility *Presented by L. Divol, Lawrence Livermore National Laboratory*
	10:10 AM	*Break*
Oral Session:	*Implosions III & LPI*	*Chair: D. E. Hinkel, Lawrence Livermore National Laboratory*
FrO-3	10:30 AM	Optical Thomson scattering on the National Ignition Facility *Presented by J. S. Ross, Lawrence Livermore National Laboratory*
FrO-4	10:50 AM	Modeling Laser-Plasma Interaction over a Suite of NIF Experiments *Presented by D. J. Strozzi, Lawrence Livermore National Laboratory*
FrO-5	11:10 AM	CH implosions are no longer vegetarian *Presented by D. E. Hinkel, Lawrence Livermore National Laboratory*
	11:10 AM	Adjourn Meeting Pick up box lunches

Ignition and pusher adiabat

B. Cheng and T.J.T. Kwan
Los Alamos National Laboratory

In the last five years, large amounts of high quality experimental data in inertial confinement fusion (ICF) were produced at the National Ignition Facility (NIF). From the NIF data, we have significantly advanced our scientific understanding of the physics of thermonuclear (TN) ignition in ICF and identified the critical physical issues important to achieve ignition, such as, implosion energetics, pusher adiabat, tamping effects in fuel confinement, and the confinement time. In this talk, we will present recently developed TN ignition theory and implosion scaling laws [1, 2] characterizing the thermodynamic properties of the hot spot and the TN ignition metrics at NIF. We compare our theoretical predictions with NIF data that show a good agreement between theory and experiments. We will also demonstrate the fundamental effects of the pusher adiabat on the energy partition between the cold shell and the hot deuterium-tritium and on the neutron yields of the ICF capsules. Applications [3, 4] to NIF experiments and physical explanations for the discrepancies among theory, data and simulations will be presented. Technology challenges, the laser energy required for achieving ignition at NIF, possible path forward, 3-D effects, and improvements to reach high yields are discussed (LA-UR-17-23655).

This work conducted under the auspices of the U.S. Department of Energy by the Los Alamos National Laboratory under Contract No. W-7405-ENG-36.

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Hybrid Drive on the National Ignition Facility

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We present an alternative inertial confinement fusion (ICF) ignition concept for the National Ignition Facility (NIF) [Miller, 2004]. This concept capitalizes on the flexibility of utilizing two independent drivers, the Northern and Southern hemispheres of the NIF laser, to separate the compression and ignition stages of an ICF implosion. One hemisphere will indirectly-drive [Lindl, 1998] one section of the capsule within a halfraum, while the other section is imploded via radial-direct-drive Shock Ignition [Betti, 2007] from the other hemisphere. The Hybrid Drive concept potentially offers the symmetry advantages of indirect-drive for fuel assembly together with the efficiency of radial-direct-drive Shock Ignition in a capsule with thick fuel layers. Given the concept's ability to separate the compression and ignition stages of an ICF implosion, each side can be tailored to a specific task; the indirectly-driven side can be optimized for a slow and stable implosion, while the directly-driven side can be optimized to provide the spark necessary for fusion burn.

Optimization scans over the multitude of design parameters will be presented, illustrating our choices in target geometry and composition. These scans are executed with the radiation hydrodynamic code HYDRA [Marinak, 2001] in a 2D Eulerian mode utilizing implicit monte-carlo radiation transport and 3D laser ray-tracing. This work will present the latest in our understanding of this highly dynamic system and point design requirements.

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The latest on High-Density Carbon Capsules implosions at the National Ignition Facility

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[2] General Atomics, San Diego, California, USA
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We are in the third year of testing high density carbon (HDC) as an ablator for Inertial confinement fusion on the National Ignition Facility (NIF). A key advantage of HDC over plastic (CH) is its higher density (3.48 g/cc vs 1.04 g/cc), which allows for HDC ablator shells 1/3 the thickness of CH shells. This translates into a short laser pulse, typically less than 8 ns, and opens up the operating space for new hohlraum design in the indirect drive ICF scheme.

I will report on the most recent effort at controlling the trajectory and symmetry of an HDC implosion in a low gasfill (0.3 mg/cc He) bare depleted uranium hohlraum. First, I will describe the trade-offs for the choice of hohlraum, capsule geometry and laser pulse to drive a 3-shock-ignition relevant implosion. We have demonstrated symmetry control at convergence 1; 3-5; 12 and 27 to better than +/- 5 μm using a succession of experimental platforms.

The corresponding cryogenic layered DT implosion yielded ~ 7e15 neutrons with a down-scattered ratio ≈ 3.2%, using a 1MJ laser pulse, roughly half of the energy NIF can deliver. I will report on our current attempt at achieving a higher yield (> 1e16 neutrons) by scaling up the system and using a 1.5 MJ pulse. I will describe the challenges of a scale-up and discuss the impact of extrinsic perturbations on the implosion performance.

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Optical Thomson scattering on the National Ignition Facility*

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[5]*SLAC National Accelerator Laboratory, Menlo Park, California, USA*

An Optical Thomson scattering diagnostic has been designed, built and fielded on the National Ignition Facility (NIF) to characterize underdense plasmas. The system spatially and temporally resolves Thomson scattered light from laser driven targets. The diagnostic design allows operation with different probe laser wavelengths. A deep-UV probe beam (λ_0 ~210 nm) is currently being developed for Thomson scatter from ICF hohlraums with an electron plasma density of ~5×10^{20} cm^{-3} while a 3ω probe is currently being used for plasma densities of ~1×10^{19} cm^{-3}. The system fields two spectrometers: the first to resolve Thomson scattering from ion acoustic fluctuations, with spectral resolution of $\delta\lambda/\lambda = 9.5\text{x}10^{-6}$ and the second to resolve scattering from electron plasma fluctuations with resolution of $\delta\lambda/\lambda = 0.0014$. We report on the design of the system and initial experimental results for different target configurations. The status of the dedicated Thomson scattering probe laser will also be presented.

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Modeling Laser-Plasma Interaction over a Suite of NIF Experiments

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We are undertaking a systematic effort to understand laser-plasma interaction (LPI) data on NIF indirect-drive experiments since 2009. This ranges from shots with low to high crossed-beam energy transfer (CBET), low to high inner-beam Raman scattering, and low to high outer-beam Brillouin scattering. For this study, LLNL's "state of the art" radiation-hydrodynamic simulation methodology is employed [1] in the Lasnex simulation code [2]. This entails converged numerical resolution, an improved DCA model for coronal ($n_e < n_{crit}$, $T_e > 1$ keV) gold opacity and emissivity, and electron heat flux that is significantly limited below the Spitzer-Harm result (to ~ 0.03X the free-streaming value $n_e T_e^{3/2} m_e^{-1/2}$), and the "inline" CBET model [3]. The rad-hydro results provide plasma conditions for subsequent LPI analysis, namely ray-based linear instability gains [4], and much more advanced simulations with the paraxial-envelope propagation code pF3D [5]. Our goal is to accurately model the absolute reflectivity levels, versus time, for different laser cones and different shots. Simulated scatter-light spectra will also be compared to experimental data, to determine if the plasma conditions are consistent. If successful, this will provide a tool to assess LPI in new target designs where LPI is a possible concern, such as those with > 2 MJ of 3ω laser energy, a 2ω "green" laser, or innovative hohlraum concepts.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

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CH implosions are no longer vegetarian*

D. E. Hinkel, T. Döppner, L. C. Jarrott, A. L. Kritcher, J. E. Ralph, C. S. Goyon,
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Improvements in the radiation environment of CH implosions [1], i.e., the hohlraum, have resulted in near-record hot spot pressures. Recent implosions use a hohlraum that, compared to the previous high gas-fill hohlraum, is 1.18x larger (which increases the case-to-capsule ratio, CCR, from 2.6 to 3.0), and is fielded with a lower gas fill density (0.6 mg/cc vs 1.6 mg/cc). In addition, these hohlraums are fielded using zero wavelength separation between inner and outer beams to minimize spatio-temporal variations in intensity caused by cross-beam energy transfer [2]. These modifications have helped to improve symmetry control of CH implosions. Additionally, laser energy coupling to the hohlraum is increased, most notably with reduced SRS. Further, the level of preheating hot electrons is reduced substantially and is now well within ignition specification.

Using this hohlraum, the size of the capsule was reduced to 90% of its previous dimensions, which further increases the case-to-capsule ratio (CCR) from 3.0 to 3.36. This results in a change in implosion symmetry from oblate (pancaked), to prolate (sausaged), at 33% cone fraction in laser power. Simulation analyses highlight improved inner beam propagation as the cause of this symmetry change.

These CH implosions have achieved a near-record 240 Gbar in stagnation pressure, with an accompanying relative increase in fusion yield, producing the highest yield for CH at this power and energy. Future experiments will focus on making the implosion more spherical as well as scaling up in implosion velocity by increasing laser power and energy from the current levels of 360 TW and 1.4 MJ, respectively.

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