LLNL-CONF-739356

Optimizing Plasma Instability Generation to Produce High Energy Bremsstrahlung X-ray Radiation

P. Poole, R. Kirkwood, S. WIlks, M. May, K. Widmann, B. Blue

October 3, 2017

HEART
Tucson, AZ, United States
April 16, 2018 through April 20, 2018

Development of bremsstrahlung x-ray source with high fluence at 50 keV via plasma instability control

Patrick L. Poole
Lawrence Livermore National Laboratory, 7000 East Ave. Livermore CA 94551
(925)-423-4383 poole11@llnl.gov

Robert Kirkwood
kirkwood1@llnl.gov

Scott Wilks
wilks1@llnl.gov

G. E. Kemp
kemp11@llnl.gov

Mark May
may13@llnl.gov

Dan Thorn
thorn9@llnl.gov

Klaus Widmann
widmann1@llnl.gov

B. E. Blue
blue3@llnl.gov
Lawrence Livermore National Laboratory, 7000 East Ave. Livermore CA 94551

Unlimited Release 35 words or less abstract:
Experimental results demonstrating 50+ keV x-ray yield enhancement on the Omega laser facility will be shown, achieved by optimizing conditions for plasma instability generation leading to a bremsstrahlung x-ray spectrum.

Classification level of final presentation/poster: ☒ Unclassified ☐ Classified

Presentation Preference: ☒ Oral ☐ Poster ☐ Computer Demo

Computer Demonstration Objective: Click here to enter text.

Sponsor/Approver: This work performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC-07NA27344.
LLNL-CONF-739356

Optimizing plasma instability generation to produce high energy bremsstrahlung x-ray radiation

Patrick L. Poole[1*], R. Kirkwood[1], S. C. Wilks[1], G. E. Kemp[1], M. May[1], D. Thorn[1], K. Widmann[1], B. E. Blue[1]
[1]Lawrence Livermore National Laboratory, 7000 East Ave., Livermore, CA 94551
[*]poole11@llnl.gov

ABSTRACT

Experimental results demonstrating 50+ keV x-ray yield enhancement on the Omega laser facility are shown, achieved by optimizing conditions for plasma instability generation leading to a bremsstrahlung x-ray spectrum.

I. INTRODUCTION

The National Ignition Facility (NIF) laser is uniquely capable of generating large x-ray fluence with $E_{h\nu} > 1$ keV through high energy laser plasma interactions. This strength makes it valuable for several endeavors that require a tailored, high flux x-ray spectrum, including material testing and code validation in extreme radiation environments [1] as well as astrophysics [2, 3], biomedical [4], and fusion [5] applications. However, these cannot be studied fully because of difficulty generating high fluence in the 30 – 100 keV range, as can be seen in Fig.1a. The four data points represent K-shell line radiation from recent NIF shots with different elements; while these make efficient x-ray sources for radiation below 20 keV, the efficiency drops drastically for higher Z elements (dotted fit line). Pulsed power devices like the Saturn source are efficient for MeV x-rays, but not for the range desired here [6].

The resulting capability gap for high fluence x-rays in the 30 – 100 keV energy range could be filled if the typical NIF bremsstrahlung x-ray spectrum (blue line) were enhanced by the optimization of the plasma instabilities; a conservative estimate is shown by the dashed green line in Fig.1a, which would enable unique materials testing experiments to be done with a high fluence 50 keV x-ray source. To achieve this, the somewhat unorthodox experimental goal is the enhancement of plasma instabilities like Stimulated Raman Scattering (SRS) [8] which accelerate hot electrons [9] to be converted to bremsstrahlung x-rays in the high-Z hohlraum wall. Such instabilities are typically reduced on NIF by design due to their negative impact on fusion [10, 11], but using this accumulated knowledge "in reverse" for enhancement presents opportunities for unique fundamental physics exploration.

Experimental and simulation effort has begun to ascertain the optimum conditions for SRS gain and the subsequent conversion to x-ray energy in the desired spectral range. This three-stage process–laser energy conversion to plasma waves, acceleration of hot electrons by the waves, and conversion of electrons to x-rays via bremsstrahlung–must be understood in detail to tailor the resulting x-ray spectrum and yield for best results. A typical hot electron spectrum is shown in Fig.1b. Choosing plasma conditions to boost T_1, T_{hot}, or both is critical and relies on knowledge of growth rate and length scale enhancement of the laser-generated plasma waves.

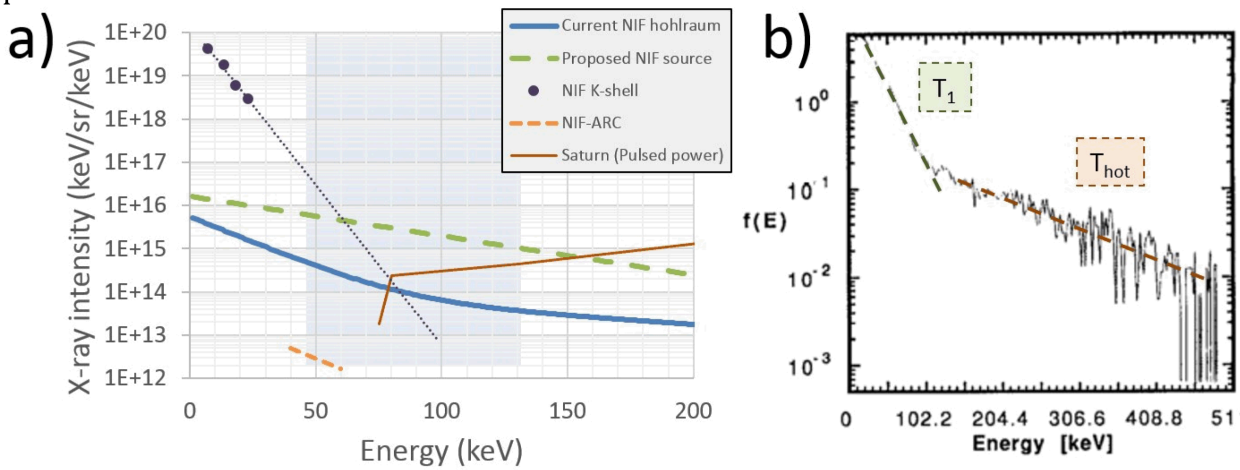

FIG. 1. a) X-ray intensities from current hohlraums [7] and shots optimizing Fe – Ag line emission on NIF compared to pulsed power x-ray sources. The dashed green curve is an estimate of possible bremsstrahlung enhancement on NIF. b) Simulation demonstrating distribution temperature and number enhancement possible through optimizing Stimulated Raman Scattering (SRS): 110 keV for $I\lambda^2 = 1 \times 10^{17} W\mu m^2/cm^2$.

II. OMEGA EXPERIMENT

A. Setup

An experiment was performed on the Omega-60 laser facility in which 40 beams were incident into Au hohlraums (2.7 mm long, 1.6 mm diameter, 1.2 mm diameter Laser Entrance Hole, 25 μm wall thickness), as depicted in Fig.2a, with up to 480 J/beam of $\lambda = 0.351$ μm light. The experimental objective was the study of optimal plasma conditions for high SRS gain and therefore high x-ray yield in the 30+ keV range; as such multiple diagnostics were fielded to examine the x-ray flux with spatial, temporal, and spectral resolution as well diagnose the Raman and Brillouin backscatter in energy, spectrum, and time.

To investigate the appropriate plasma conditions for SRS backscatter and x-ray generation, two different hohlraum fills were used: one set had SiO_2 foam at 6 mg/cc (0.2% n_{crit}), and another with 10 μm of parylene-N (CH) lining the inner wall, ablated by a pre-pulse with variable time delay before main laser drive arrival (1.0, 1.5, 2.0 ns), shown in Fig.2b. Hydrodynamic simulations (2c) were performed to judge the optimum range of delays between the pre-pulse and drive pulse for filling the hohlraum with the desired plasma density.

B. Results

Results from several x-ray and optical backscatter diagnostics will be presented in detail. The primary observation is a 10x increase in 50 keV and above x-rays was observed on the Hard X-ray Detector compared to previous direct-drive Omega shots, which is a promising result for the future extrapolation of this campaign to NIF. Analysis of other diagnostics reveals that while the CH-lined targets exhibited the most SRS backscatter, it was the

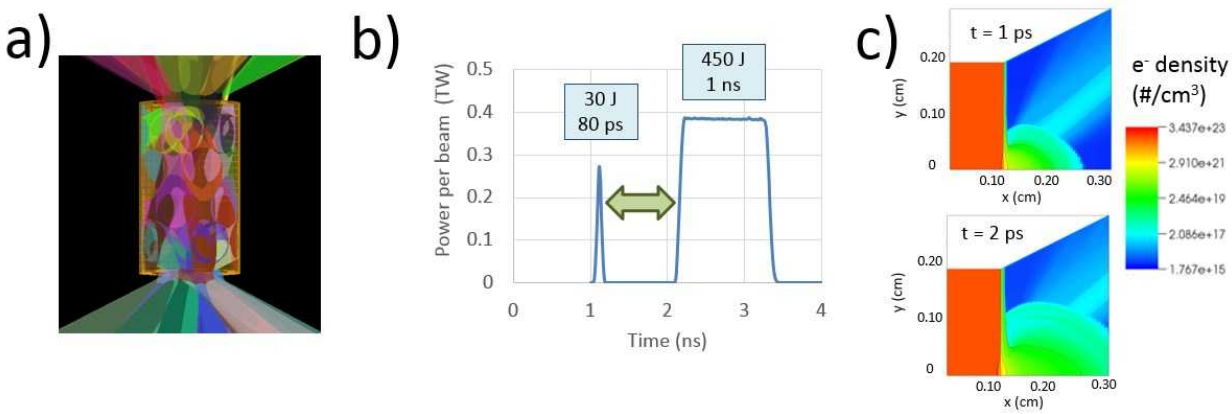

FIG. 2. a) Diagram of Au hohlraum and with 40 Omega beams incident on the inner wall. b) Laser pulse used with variable pre-pulse picket timing. c) Hydrodynamic simulations demonstrating optimal timing of pre-pulse between 1 and 2 ps to achieve desired plasma density within hohlraum.

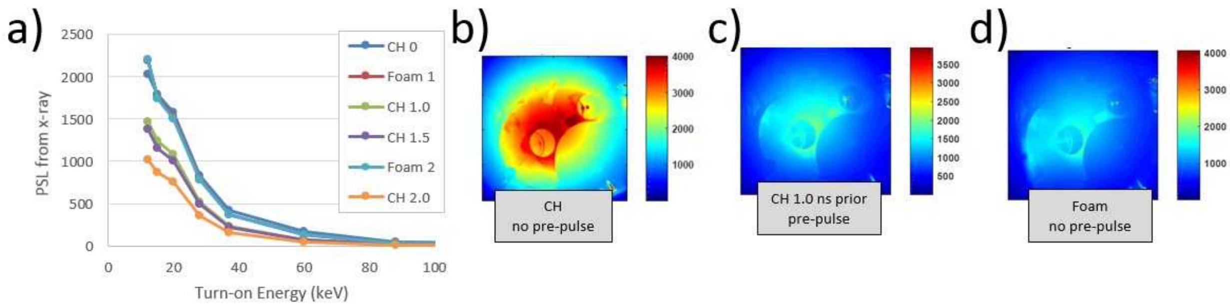

FIG. 3. Near Backscatter Imager (NBI) data shown in false-color logarithmic scale from recent Omega shots on various targets: a) no pre-pulse CH, b) 1 ns early CH, c) foam-filled. Large off-axis backscatter for the no pre-pulse CH-lined target suggests further SRS studies to determine the relationship between SRS and generated x-rays (highest on the foam target).

foam-filled and no pre-pulse CH targets which had the highest x-ray signals, an inverse relationship that ran somewhat counter to initial expectations. The x-ray signal from the HERIE diagnostics [12] is shown in Fig.3a, where the highest x-ray signal at all energies came from the foam and CH 0 (no pre-pulse) targets. One explanation of this observation lies in the directionality of optical backscatter observed: the Near Backscatter Imager (NBI) shown in

Fig.3b-d demonstrates much greater off-axis backscatter in the CH 0 target compared to the foams, despite their similar x-ray yields. These results and further simulations are informing a subsequent Omega shot day and upcoming NIF shots in 2018.

---

[1] R. C. Elton, D. Billings, J. Grun, F. C. Young, C. K. Manka, B. H. Ripin, H. R. Burris, J. Resnick, D. J. Ripin, and J. R. Millard, Journal of Applied Physics **74**, 5432 (1993).

[2] R. L. Lysak and Y. Song, Journal of Geophysical Research: Space Physics **108** (2003), 10.1029/2002JA009406, 8005.

[3] C. M. Olbert, C. R. Clearfield, N. E. Williams, J. W. Keohane, and D. A. Frail, The Astrophysical Journal Letters **554**, L205 (2001).

[4] R. Neutze, R. Wouts, D. van der Spoel, E. Weckert, and J. Hajdu, Nature **406**, 752 (2000).

[5] E. L. Dewald, M. Rosen, S. H. Glenzer, L. J. Suter, F. Girard, J. P. Jadaud, J. Schein, C. Constantin, F. Wagon, G. Huser, P. Neumayer, and O. L. Landen, Physics of Plasmas **15**, 072706 (2008).

[6] K. D. Ware, D. E. Bell, R. L. Gullickson, and I. Vitkovitsky, IEEE Transactions on Plasma Science **30**, 1733 (2002).

[7] T. D¨oppner, C. A. Thomas, L. Divol, E. L. Dewald, P. M. Celliers, D. K. Bradley, D. A. Callahan, S. N. Dixit, J. A. Harte, S. M. Glenn, S. W. Haan, N. Izumi, G. A. Kyrala, G. LaCaille, J. K. Kline, W. L. Kruer, T. Ma, A. J. MacKinnon, J. M. McNaney, N. B. Meezan,
H. F. Robey, J. D. Salmonson, L. J. Suter, G. B. Zimmerman, M. J. Edwards, B. J. MacGowan, J. D. Kilkenny, J. D. Lindl, B. M. Van Wonterghem, L. J. Atherton, E. I. Moses, S. H. Glenzer, and O. L. Landen, Phys. Rev. Lett. **108**, 135006 (2012).

[8] W. L. Kruer, *The Physics of Laser Plasma Interactions*, 3rd ed. (Westview Press, 2003).

[9] S. C. Wilks, W. L. Kruer, K. Estabrook, and A. B. Langdon, Physics of Fluids B **4** (1992).

[10] R. K. Kirkwood, J. D. Moody, J. Kline, E. Dewald, S. Glenzer, L. Divol, P. Michel, D. Hinkel, R. Berger, E. Williams, J. Milovich, L. Yin, H. Rose, B. MacGowan, O. Landen, M. Rosen, and J. Lindl, Plasma Physics and Controlled Fusion **55**, 103001 (2013).

[11] 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, Physics of Plasmas **18**, 056312 (2011), http://aip.scitation.org/doi/pdf/10.1063/1.3577836.

[12] C. D. Chen, J. A. King, M. H. Key, K. U. Akli, F. N. Beg, H. Chen, R. R. Freeman, A. Link, A. J. Mackinnon, A. G. MacPhee, P. K. Patel, M. Porkolab, R. B. Stephens, and L. D. V. Woerkom, Review of Scientific Instruments **79**, 10E305 (2008), http://dx.doi.org/10.1063/1.2964231.