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Lawrence Livermore National Laboratory

A. A. Hauer and W. W. Hsing
Los Alamos National Laboratory

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Lawrence Livermore National Laboratory, University of California Livermore, California 94551

A. A. Hauer, W. W. Hsing
Los Alamos National Laboratory, University of California
Los Alamos, New Mexico 87545

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Abstract

Experiments on Nova have demonstrated hohlraum radiation temperatures up to 300 eV and in lower temperature experiments reproducible time integrated symmetry to 1-2%. Detailed 2-D LASNEX simulations satisfactorily reproduce Nova's drive and symmetry scaling data bases. Hohlraums has been used for implosion experiments achieving convergence ratios (initial capsule radius/final fuel radius) up to 24 with high density glass surrounding a hot gas fill(1).

Radiation drive measurements and calculations on Nova

The radiation temperature in a hohlraum is determined by a balance of sources and sinks expressed by

$$\eta P_L = (A_W (1-\alpha) + A_h) \sigma T_R^4$$

The x-ray source is ηP_L where P_L is the laser power, the hole loss is $\sigma T_R^4 A_h$, and the wall loss is $(1-\alpha) \sigma T_R^4 A_W$, where A_h and A_W are the areas of the holes and wall respectively, T_R is the effective brightness temperature of the hohlraum and α is the wall albedo(2). For Nova hohlraums, α ~0.8 and the x-ray conversion efficiency η can be related to open geometry experiments.

The targets for Nova experiments are right circular cylinders 1.6 mm diameter and 2.5-2.8 mm long made of high Z material. Five beams per side, with up to 30 TW of 0.35 μm light in a 1 ns square laser pulse, are focused through the two laser entrance holes (LEH) in the ends of the cylinders onto the inside cylinder walls. Scaling is also investigated using 1.2 mm and 1.0 mm diameter targets.

The radiation temperature in the cavities is determined by observing the velocity u_s of a shock wave generated when radiation is absorbed in Al wedged and stepped witness plates. For the temperature range of these experiments, $T_R = 0.0126\, u_s^{0.63}$ where T_R is in units of eV and u_s is in units of cm/s. The shock velocity is measured with an error corresponding to ± 5 eV in T_R, by time resolving the optical emission from an Al wedged or stepped witness plate.

T_R is also measured(3) from the reradiated flux, S_r, from the x-ray heated wall using an array of x-ray diodes with a time resolution of 150 ps.

Using 1 ns constant power (square) laser pulses, T_R measured from the shock breakout as a function of average laser power is shown in Fig. 1. In smaller cylindrical cavities, we measure temperatures of 290 eV and 300 eV for a 1.2 mm and 1.0 mm diameter cavity, respectively. The present experiments significantly extend the range of radiation temperatures attained in the laboratory(4) to temperatures of interest for high gain implosions. Results of the fit from the power balance equation are the lines shown in Fig. 1 with η being 0.75, 0.65, and 0.50 for the 1.6 mm, 1.2 mm and 1.0 mm diameter cavities, respectively. The 1.6 mm cavities have also been modeled using 2-D LASNEX and are also shown as open circles in Fig.1.

In general, x-ray drive becomes easier for larger facilities, because the temperature is determined by the wall loss $1-\alpha \sim 1/T_R^{0.5}\, t^{0.5}$. For longer times, or for higher temperatures, the wall loss drops(2). For 1.6 mm cavities on Nova, t ~ 1 nsec, T ~ 260 eV and $1 - \alpha = 0.2$: in contrast the NIF will have t ~ 10 nsec and T ~ 300 eV and $1 - \alpha \sim 0.11$.

Radiation symmetry experiments and calculations

In separate experiments, we have produced nine different symmetry scaling data bases using pulse shapes from 1 nsec flat top to 3.2 ns shaped pulses, and pure gold and lined hohlraums. In some cases, we varied the length of the hohlraum with the pointing so that the beams always cross in the plane of the laser entrance hole (LEH).

For the 1500Å of nickel lined series for example, the hohlraums were 1.6 mm diameter with 1.2 mm diameter laser entrance holes. In this series the hohlraum length was varied with pointing such that the beams always crossed in the plane of the LEH. Drive symmetry was measured by imploding a capsule with a convergence of ~8 and measuring the shape of the imploded capsule(5,6). Figure 2 displays the results of this experiment and compares it to our modeling. The solid circles are "distortions' (ratios of the FWHM's of the x-ray images) from our experiments as a function of beam pointing. The modeling's distortions are the open circles. Clearly we can control Nova symmetry by varying the beam pointing. For this series, the pointing of best symmetry is ~1200 μm in experiment and ~1150 μm in simulation.

Figure 3 summarizes our ability to simulate with LASNEX(7) the pointing of best symmetry over this wide range of experiments.

The fundamental asymmetry in a Nova-like hohlraum is a long wavelength, pole to waist flux variation which varies like the P2 legendre polynomial. In a spherical hohlraum, the P2 component of capsule flux vanishes when the P2 component of the source flux is zero at the polar angle where P2 is zero, 54.7°. A laser entrance hole modifies this and the center of emissivity in a spherical hohlraum must be at about 44° and in our more detailed LASNEX simulations, which include higher l-mode components, volume emission and mode-coupling due to having a sphere inside a cylinder, we find the pole:waist fluxes are balanced when the center of emissivity is at ~48°.

Spot motion, the migration of the radiation production region to smaller polar angles, causes a simulated Nova-type hohlraum to have an equator-high to pole-high asymmetry swing as the pulse becomes longer. For all three pulse shapes we find that near the pointing of best symmetry the center of emissivity sweeps through the "optimal angle" (where pole pressure = equator pressure; ~48° for these hohlraums) when ~50% of a shape's useful energy has been delivered.

Hot spot implosion experiments

Our best implosion targets were x-ray driven, 180 μm o.d., 5 μm thick gas filled glass microballoons overcoated with 37 μm of plastic. Fill pressures varied from 25-200 atm of deuterium. Ten Nova beams (21 kJ) produced a uniform x-ray flux on the capsule surface. The radiation brightness temperature had a 100 eV foot, rising to 210 eV peak in 1.6 nsec, chosen to optimize the pressure-density trajectory of the capsule compression, giving 8 Mbar ablation pressure at the foot of the pulse and 110 Mbar at the peak of the pulse.

Convergence of these capsules is limited by the x-ray drive symmetry both inherent to the hohlraum and due to random variations from imprecise laser beam-to-beam power balance and pointing. We maintain tolerances of 8% (RMS) beam-to-beam power balance during the foot of the laser pulse and 4% power balance during the peak, giving an x-ray power balance on the capsule uniform to 2% (RMS) at peak power and 4% in the foot.

Burn averaged fuel density and capsule convergence were determined from measurements of fuel areal density, giving densities up to 19 ± 1.5 gm/cm^3, with convergences up to 24, in agreement with simulations. Primary neutron yield, pusher areal density, burn duration, burn time, and fuel ion temperature were also measured.

Primary neutron yields for these implosions were in agreement with simulations using the Haan mix model(8). Measured fuel ion temperatures were 0.9 ± 0.4 keV corresponding to a final fuel pressure of 16 Gbar. Glass shell densities were measured at 160 ± 20 g/cm^3. The burn duration for the 100 atm capsules was measured to be 50 ± 15 ps giving measured values of $n\tau = 1.9 \times 10^{14}$ s/cm^3.

In conclusion, the x-ray temperature and degree of symmetry in Nova implosions are accurately modeled. X-ray driven implosion have demonstrated radial convergences at a level close to the convergences required for a ignition capsules.

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References

[1] K. A. Brueckner and S. Jorna, Rev. Mod. Phys. 46, 325 (1974).

[2] R. Sigel, et. al., Phys. Rev. A 38, 5779 (1988).

[3] H. N. Kornblum, R. L. Kauffman, and J. A. Smith, Rev. Sci. Instrum. 57, 2179 (1986).

[4] H. Nishimura et. al., Phys. Rev., A44, 8323 (1991).

[5] J. D.Kilkenny et. al., Plasma Physics and Controlled Thermonuclear Fusion Research 1988, 3, p29, IAEA Vienna 1989.

[6] J. D. Kilkenny, Rev. Sci. Instrumen., 63, 4688 (1992).

[7] G. Zimmerman and W. Kruer, Comments Plasma Phys. Controlled Fusion 2, 85 (1975).

[8] S. W. Haan, Phys. Rev. A39, 5812 (1989).

Figure Captions

Figure 1 Radiation temperature as a function of laser power for 1 ns laser pulses. The experimental results for 1.6 mm, 1.2 mm and 1.0 mm diameter cavities are shown by the closed circles, triangles and squares respectively. LASNEX calculations are open circles. The lines are fits to the data using the power balance equation.

Figure 2 Capsule image distortion vs. initial pointing from a series using Ni-lined hohlraums irradiated by a 2.2 nsec shaped laser pulse, ps22. Inset: Relative laser power vs time for ps22.

Figure 3 Pointing of best symmetry in experiment vs. pointing of best symmetry from our modeling for 1 ns flat top, 2.2 ns 3:1 ps 22, and 3.2 ns 5:1 ps 32. The longer the pulse shape, the further in we must move the beams to get good symmetry.

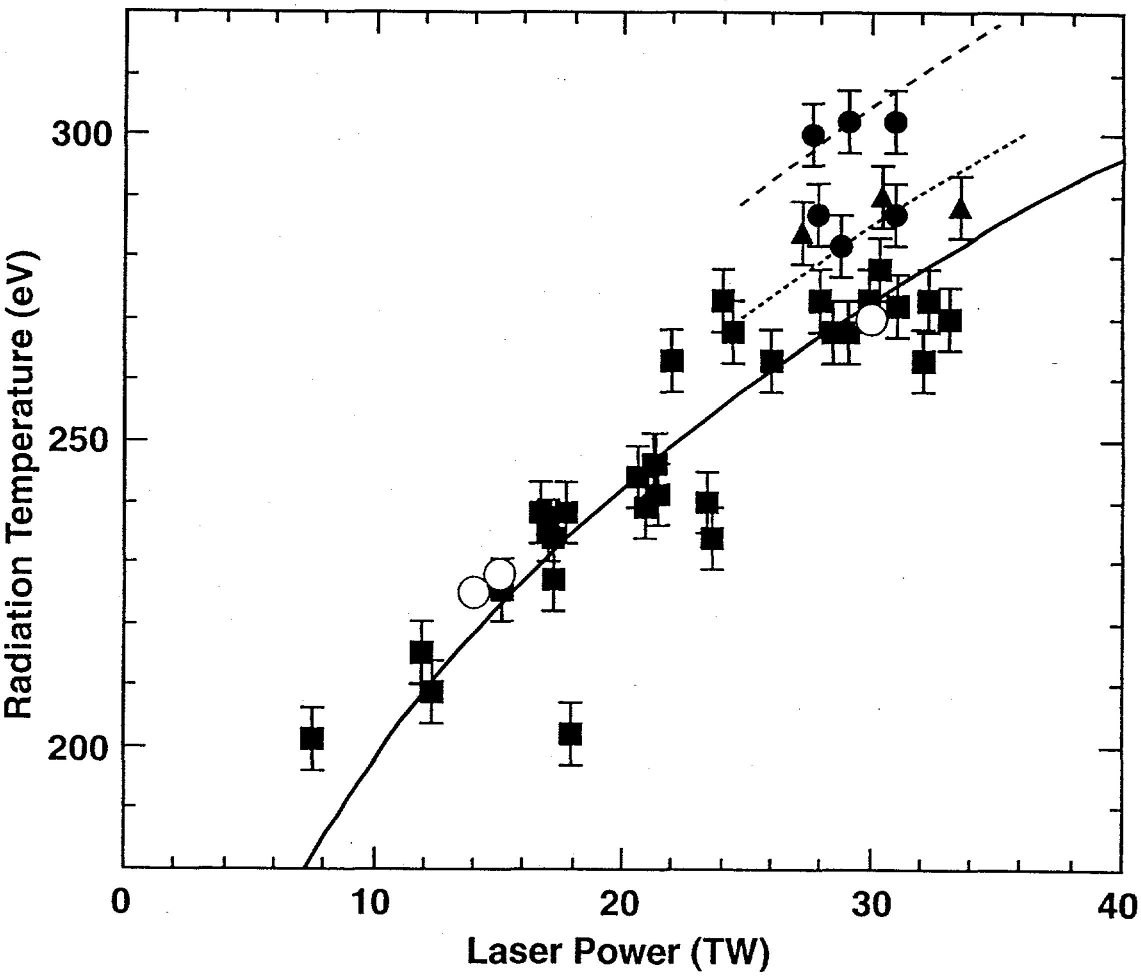

Figure 3 Figure 1
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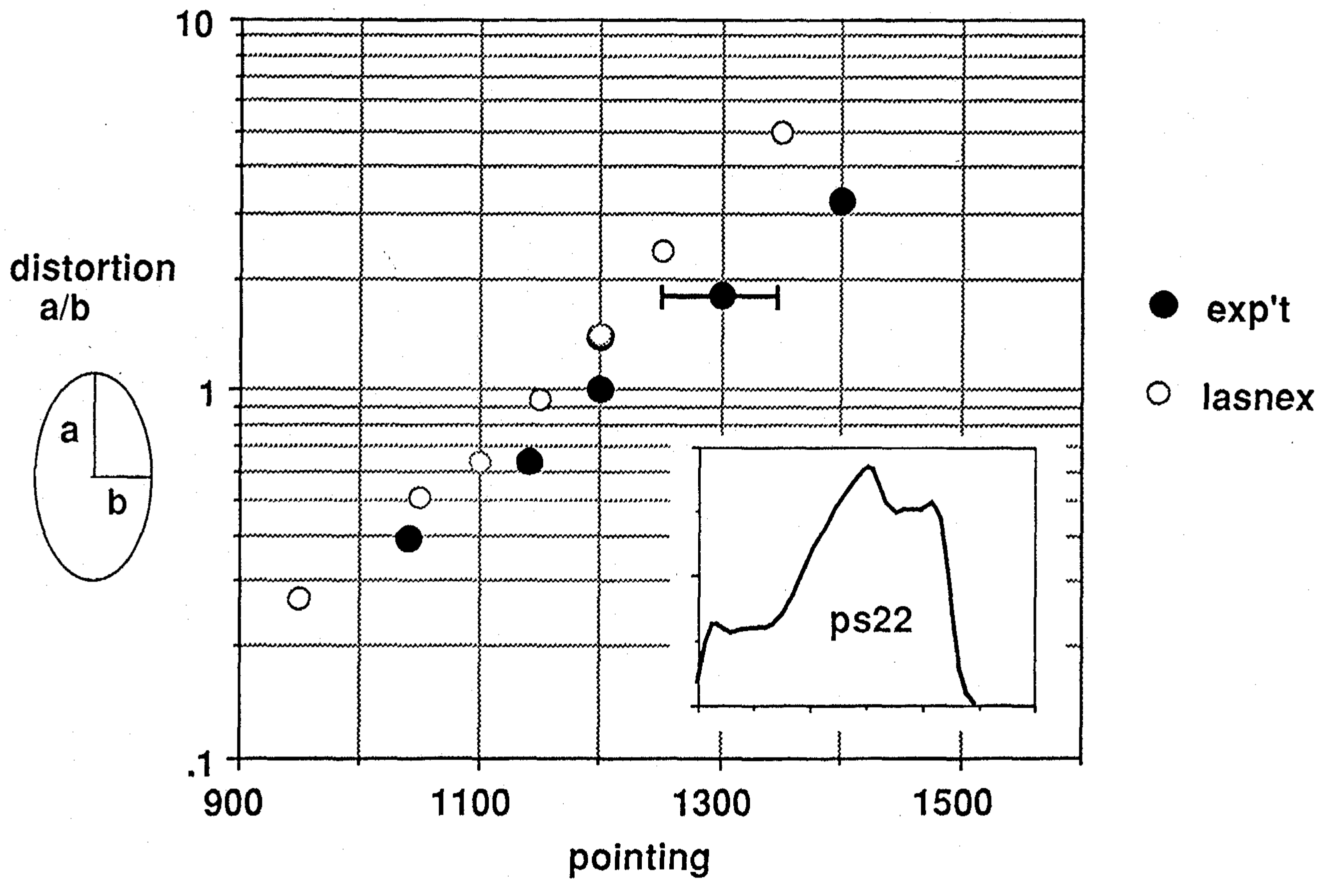
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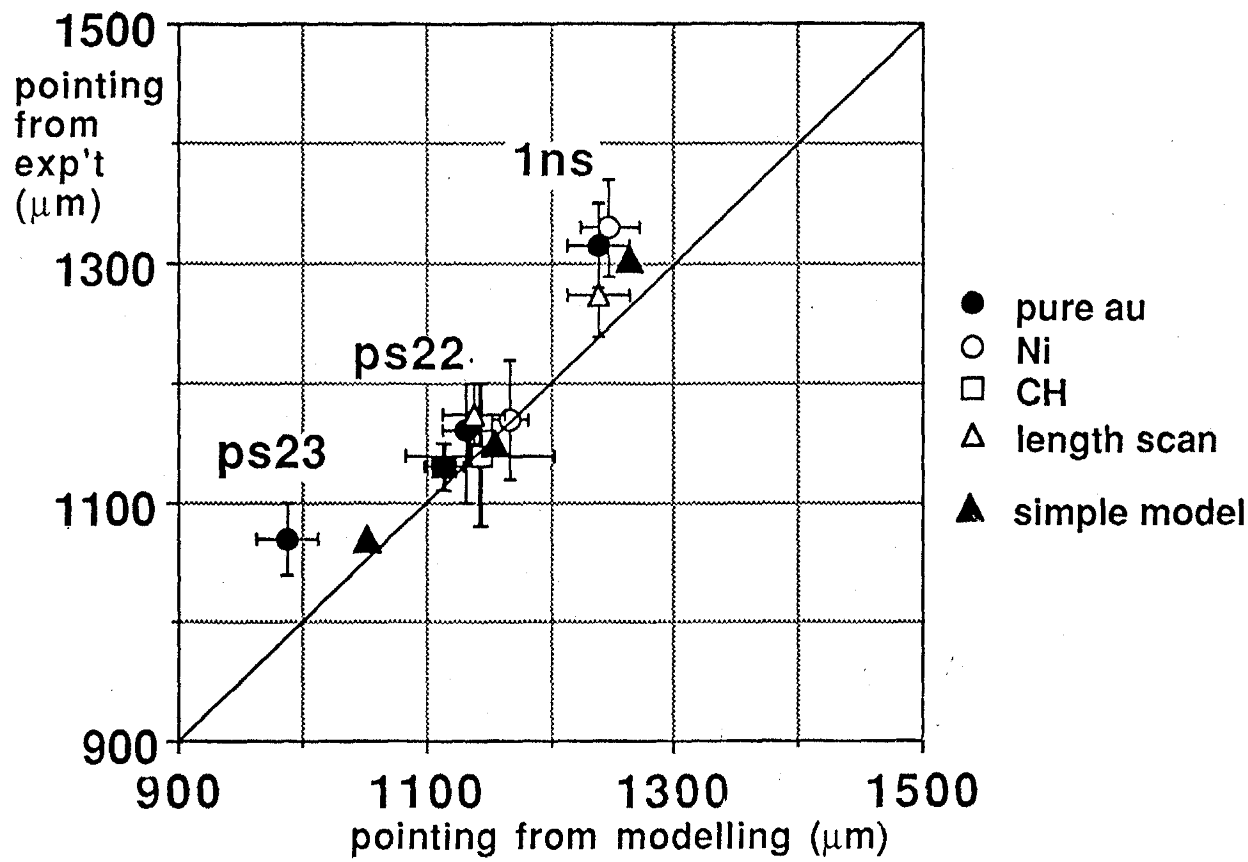
Figure 2

figure 3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