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X-ray Imaging of Uniform Large Scale-Length Plasmas Created from Gas-Filled Targets on Nova

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X-ray imaging of uniform large scale-length plasmas created from gas-filled targets on Nova

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We report on the production and characterization of large scale-length plasmas created by illuminating gas-filled thin-walled balloon-like targets using the Nova laser. The targets consisted of a 4-5000 Å skin surrounding 1 atm of neopentane which when ionized becomes a plasma with 10^{21} electrons/cm^3. Results are presented from x-ray imaging used to evaluate the uniformity of the plasma. The most uniform plasmas were produced by illuminating the target with large converging beams that overlapped to cover most of the surface of the gasbag. An alternate focus geometry using small beam spots resulted in a less uniform plasma with low density holes in it.

Large uniform plasmas have been created using the Nova laser in order to study laser-plasma interactions from a large scale-length plasma.[1] These plasmas have been created by illuminating gas-filled balloon-like targets (gasbags) with ten Nova beams. The gasbag target consists of a 400 μm thick aluminum (Al) washer with an inside diameter of 2.75 mm and an

8000 Å thick polyimide layer[2] glued to each face. The target is inflated to stretch the polyimide to a near-spherical shape and a thickness of 4-5000 Å (Fig. 1). The gasbags were filled with 1 atm of neopentane (C_5H_{12}), resulting in a plasma electron density of 10^{21} cm^{-3} when the gas is fully ionized. This electron density is about 0.1 times the critical density (n_c) for the 0.35 μm laser wavelength (3ω). In this paper, we present x-ray images that were recorded in order to characterize the uniformity of the gasbag plasma.

The gasbag targets are illuminated with 25 kJ at 3ω in a 1 ns square pulse. The laser ionizes the gas and heats the plasma to an electron temperature of 3 keV.[3] This temperature was measured by looking at the ratios of x-ray spectral line emission from various high-Z dopants such as argon and chlorine gas dopants or titanium and chromium coated on carbon fibers and placed inside the target.

In order to generate a uniform plasma from the gasbag target, various laser focusing geometries were tested. The gasbags were uniformly illuminated with large spot, converging focus beams that were 1.7 mm in diameter and overlapped to cover most of the target surface. An alternative geometry uses small spot, diverging focus beams that placed 500 μm beam spots on the surface of the target. With the large spots, the laser intensity was approximately 1.3×10^{14} W/cm^2, and almost the full surface of the polyimide skin was directly illuminated and heated. With the 500 μm spots, the laser intensity was 1.5×10^{15} W/cm^2 at the surface of the gasbag, illuminating only a small fraction of the polyimide skin at the surface.

Time-resolved x-ray pinhole images of the gasbags were recorded using gated microchannel plate striplines. Images of the gasbags taken parallel to the washer, as shown in Fig. 1, were recorded using the Gated X-ray Imager (GXI)[4] consisting of four parallel striplines on a microchannel plate. The images were filtered with 75 μm beryllium (Be) and 6 μm Al or 150 μm Be to transmit photon energies >3 keV. Images looking face-on at the washer were recorded using the West Axial Imager (WAX).[5] The WAX consists of a serpentine stripline coated onto a microchannel plate detector. It was filtered with 500 μm Be. The gate time for both the x-ray imagers was 80-100 ps. Images were taken from orthogonal views at a range of times during and after the laser pulse.

When a gasbag is illuminated with large beam spots, the full skin is directly heated, as shown in Figs. 2a and 3a for C_5H_{12} filled gasbags. Figure 2 shows a sequence of gated images recorded with the GXI at different times. Figure 3 shows a sequence of images recorded with the WAX. The solid density skin lights up at the start of the pulse. Gated images show that it takes approximately 200 ps to burn through the skin into the plasma. This is consistent with the measured time-dependent laser reflectivity of the plasma. As the skin becomes less dense and transparent to the laser, the reflectivity is reduced.

As the skin blows down, the laser starts to propagate into the gas. Lineouts of the x-ray emission profile (integrated along a line-of sight) show that the center of the gasbag is heated towards the end of the 1 ns pulse (Fig. 4). The WAX images show a ring of enhanced x-ray emission that has five-fold symmetry. This propagates slowly inward, as shown in the sequence of images in Fig. 3, reaching the center at approximately 1 ns after the laser turns off, near t=2 ns.

Streaked images of the gasbag plasma recorded from the direction of the GXI also show the heating and uniformity of the plasma with a region of enhanced emission that propagates into the plasma. Figure 5 shows the time-history of the position of peak x-ray emission as it propagates towards the washer plane in the streaked image from a gasbag. Overlaid on the graph is the time-history of the diameter of the ring of bright x-ray emission recorded in a sequence of gated WAX images from several gasbags. The streak camera shows this peak in emission propagates towards the plane of the washer at 0.8 mm/ns. The speed of the ring of emission towards the center is 0.5 mm/ns.

Computer simulations of the laser interaction with a gasbag target were done using the Lagrangian hydrodynamics code LASNEX,[6] and then the output was post-processed for comparison with the x-ray images. The gas-filled target was modeled with the polyimide skin using cylindrical symmetry in order to simulate the uniform laser illumination, and the laser energy absorption was modeled using inverse Bremsstrahlung radiation and resonance absorption. With this model, the polyimide skin explodes and becomes transparent to the laser as it is directly illuminated, and launches a blast wave into the plasma. The laser ionizes and heats the gas as it propagates into the target. Thermal conduction transports the energy laterally, resulting in a uniformly heated plasma. The higher density due to the blast wave appears in the simulated x-ray images as a symmetric ring of enhanced x-ray emission that propagates slowly into the plasma. Lineouts of the x-ray emission are shown in Fig. 6 for comparison with the experiment (Fig. 4). Viewed from the axial direction, this ring of emission gets to the center of the target at approximately t=2 ns, consistent with the experiment.

In contrast to the large beam spot illumination, several gasbags were illuminated with 500 μm spots. Figure 7a shows a gated x-ray image of a gasbag illuminated with small beam spots. This image shows regions of reduced x-ray emission that appear where the beams were incident on the target. A simulated image is shown for comparison in Fig. 7b. In order to simulate the illumination geometry of the small beam spots, the 3-dimensional geometry of the gasbag was modeled in segments The interaction of each beam was modeled in two dimensions using a 1/10 sphere, and then x-ray images were calculated from the superposition of the elements. In this case, the laser directly heats narrow channels of plasma in the gasbag, causing flow outwards to leave low density holes which appear as regions of reduced x-ray emission in the images.

Gasbag targets have successfully been illuminated in the Nova target chamber in order to generate a large, uniform plasma. In the experiments described in this paper, the electron density of the plasma is 0.1 n_c for 3ω laser light. This plasma is used for laser-plasma interaction experiments in order to study the laser absorption and scatter in underdense plasmas near and above instability thresholds. The gas-fill in the gasbag targets may be varied in composition and pressure in order to sample a range of plasma conditions.

X-ray imaging shows that the plasma formed by heating the gasbag with 1.7 mm beam spots results in a large plasma with a uniform density plateau. The uniform density region is blown down by a blast wave that propagates into the plasma due to the ablation of the skin. For gasbag targets illuminated with small beam spots, x-ray imaging shows a non-uniform plasma with low density holes that are formed. In each case, the x-ray images are similar to the simulated images.

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References:

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3 D.W. Phillion *et al*, Bull. Am. Phys. Soc. 38, 1915 (1993).

4 F. Ze *et al*, Rev. Sci. Instrum. **63**, 5124 (1992).

5 P.M. Bell, J.D. Kilkenney, G. Power, R. Bonner, and D.K. Bradley, in "Ultrahigh Speed and High-Speed Photography, Photonics, and Videography '89", SPIE 1155 (SPIE, Bellingham, WA, 1989), pp. 430-444.

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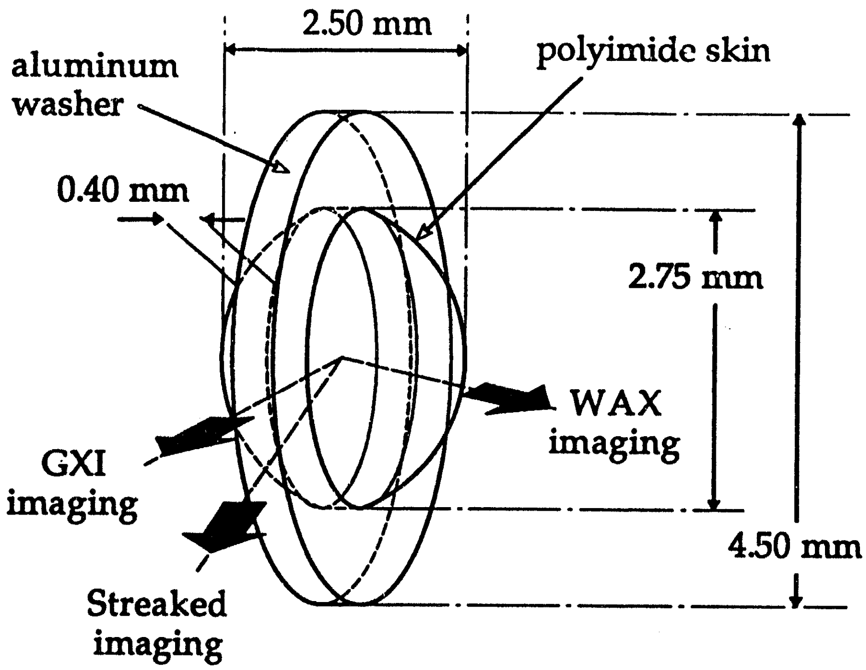
List of Figures: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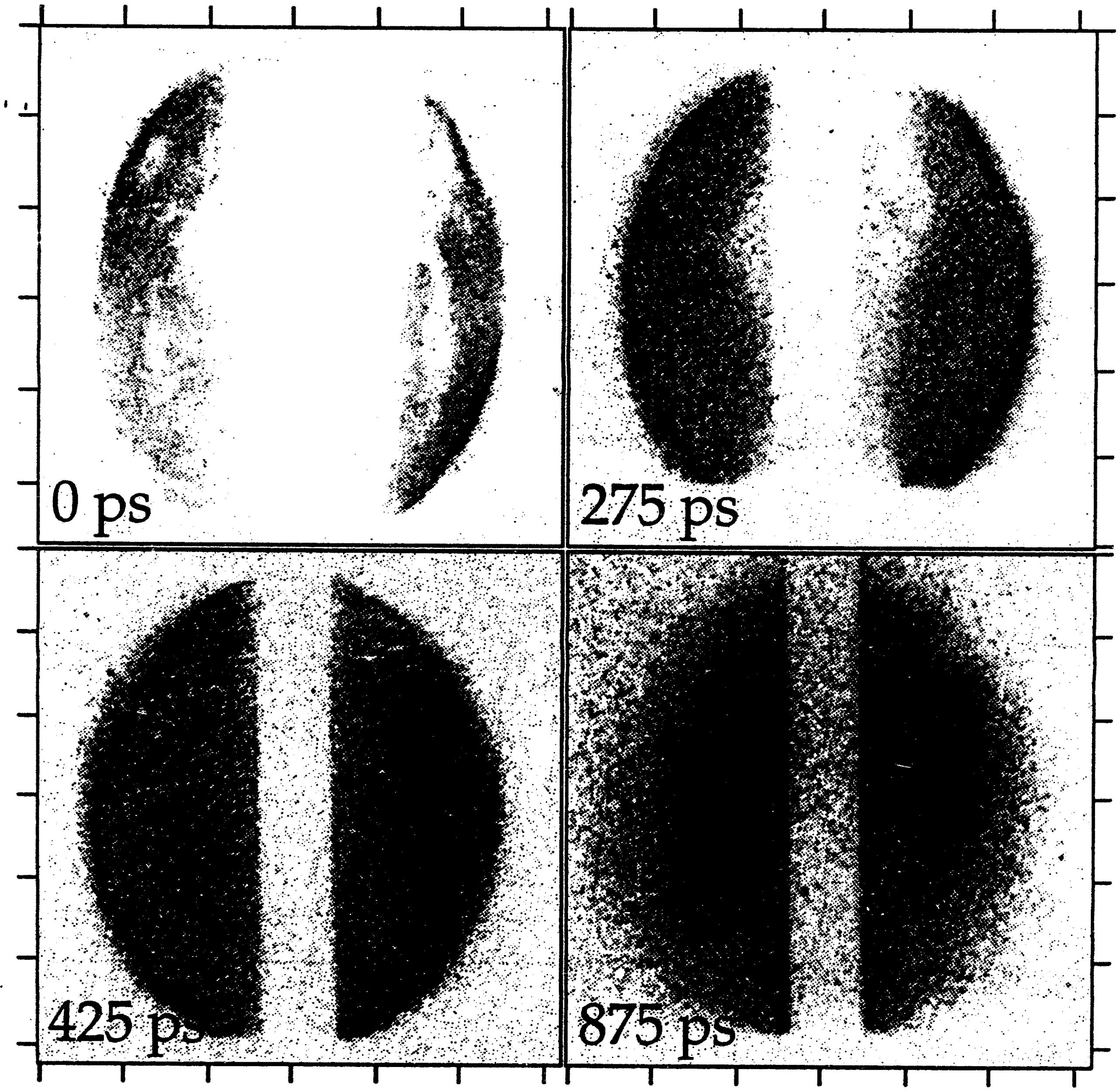
aluminum washer
polyimide skin
0.40 mm
2.75 mm
WAX imaging
GXI imaging
4.50 mm
Streaked imaging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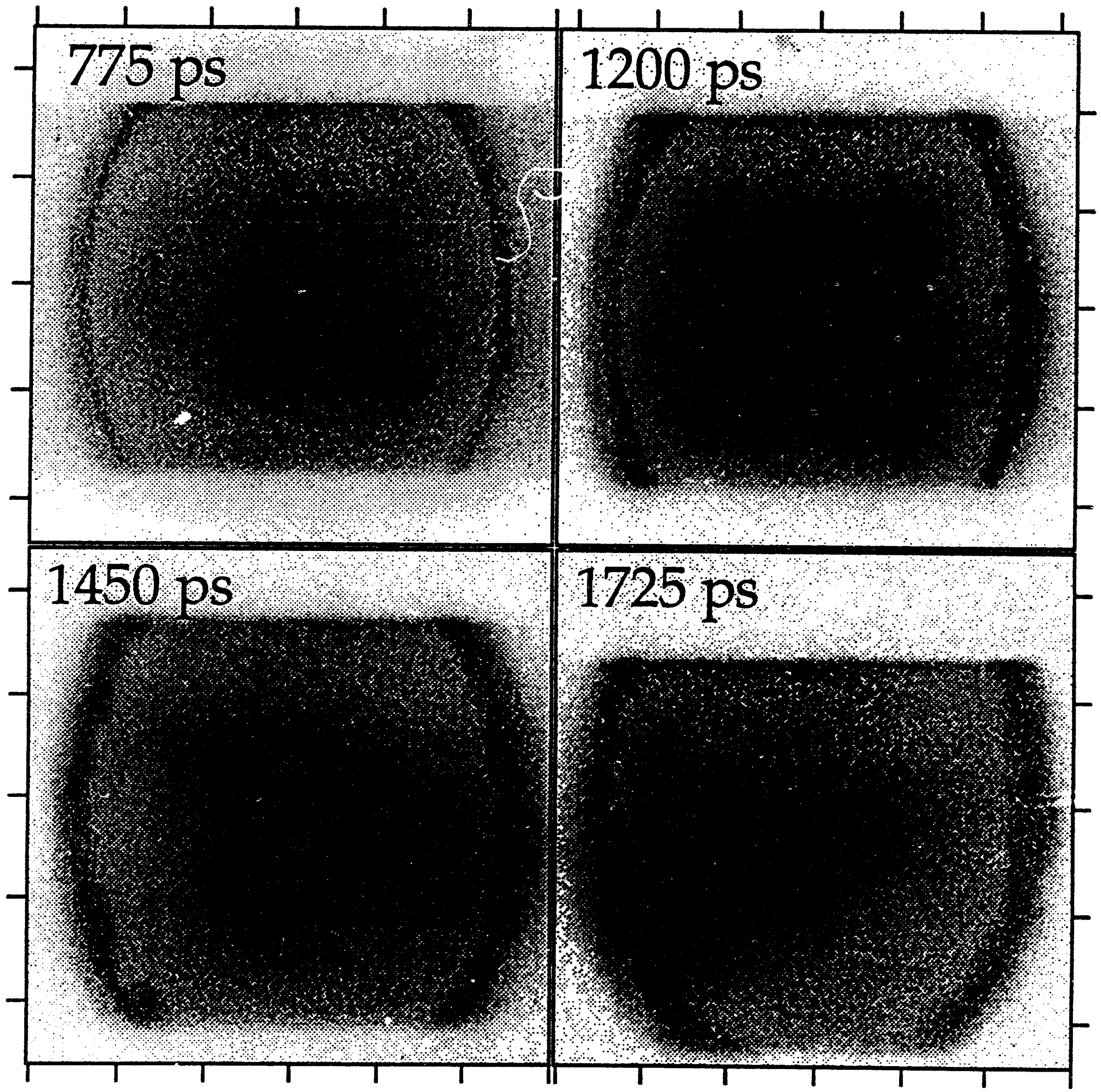

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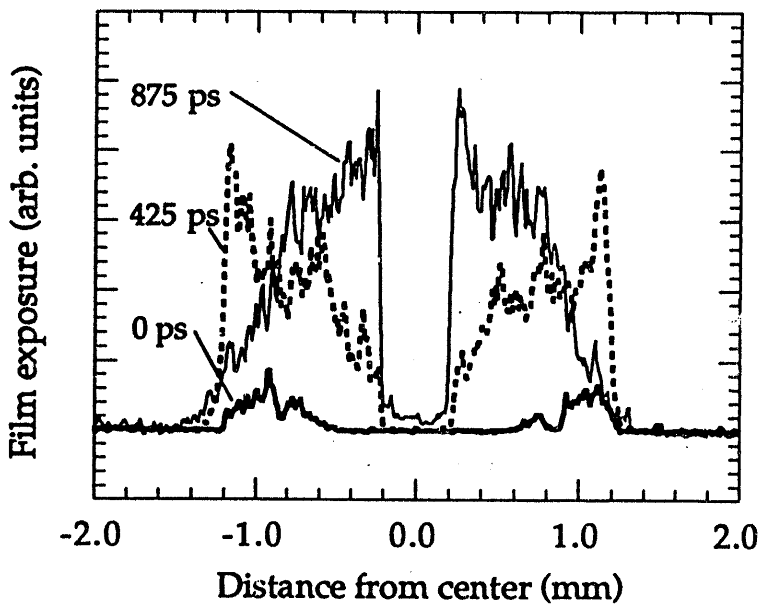
1725 ps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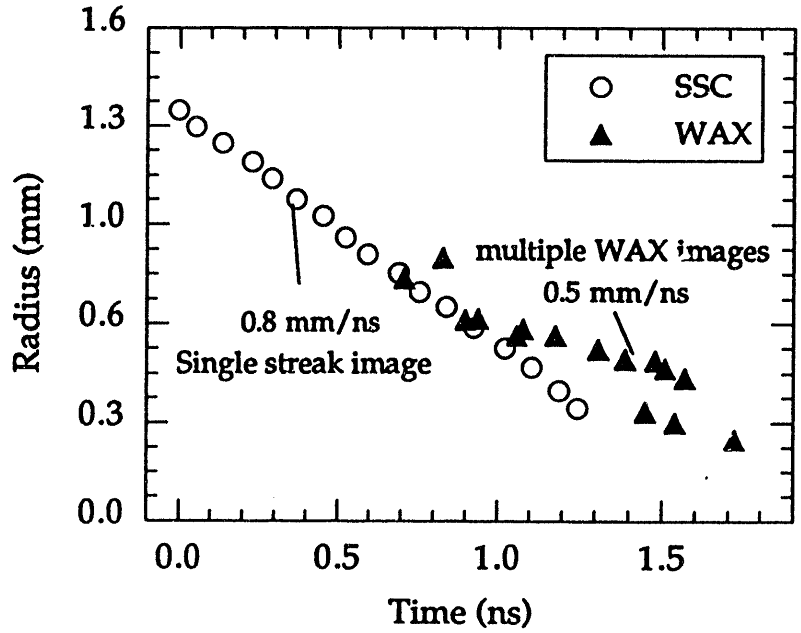
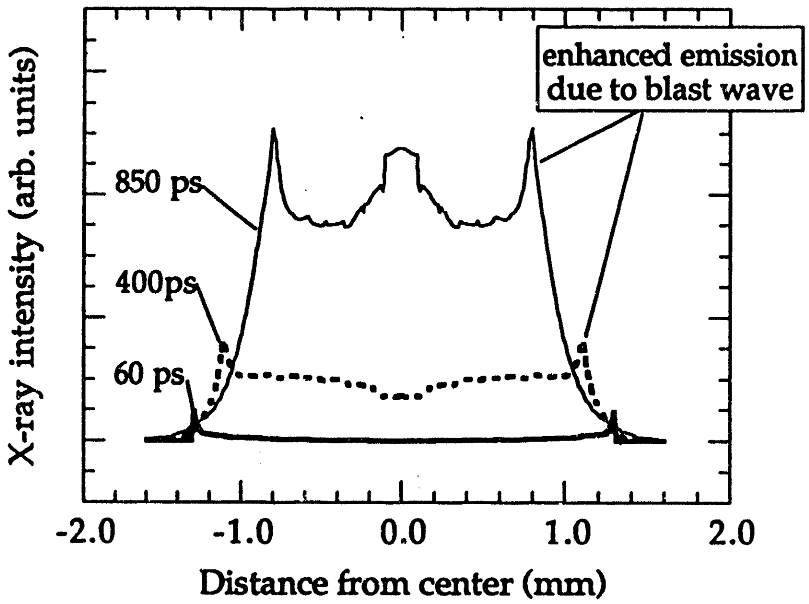
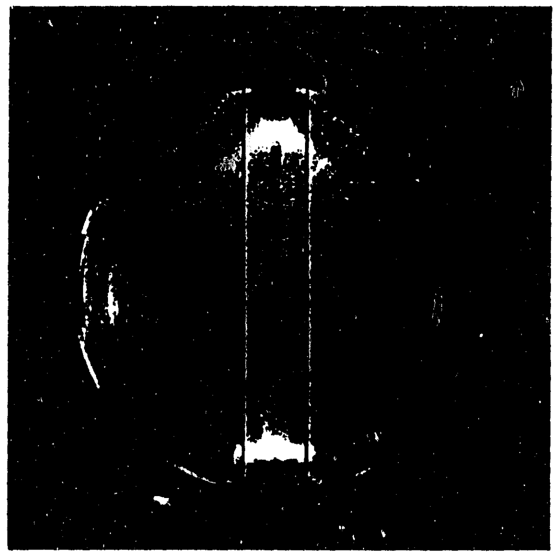
425 ps
0 ps
-2.0
-1.0
0.0
1.0
2.0
Distance from center (mm)



SSC
WAX
multiple WAX images
0.5 mm/ns
0.8 mm/ns
Single streak image
Radius (mm)
Time (ns)
1.6
1.3
1.0
0.6
0.3
0.0
0.0
0.5
1.0
1.5



enhanced emission
due to blast wave
850 ps
400ps
60 ps
X-ray intensity (arb. units)
-2.0
-1.0
0.0
1.0
2.0
Distance from center (mm)

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