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TITLE: Recent Laser Experiments on the Aurora KrF/ICF Laser System

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Recent Laser Experiments on the Aurora KrF/ICF Laser System

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Abstract

The Aurora KrF/ICF Laser Facility at Los Alamos is operational at the kilojoule-level for both laser and target experiments. We report on recent laser experiments on the system and resulting system improvements.

Summary

Aurora is the Los Alamos National Laboratory short-pulse, high-power, krypton-fluoride (KrF) laser system for inertial confinement fusion (ICF) research. The system employs optical angular multiplexing and serial amplification by electron-beam-driven KrF laser amplifiers. In the present configuration 48 5-nsec pulses are multiplexed and amplified. These pulses are demultiplexed using suitable time-of-flight delays and delivered simultaneously to target. During the last year the Aurora laser system has been operational at the kilojoule-level and has been used for both laser and target physics experiments. In this paper we review the present configuration of the system and report on laser experiments and the resulting improvements in the system. Descriptions of the front end, the four laser amplifiers, and the optical system are included. Experiments reported include amplifier small signal gain, energy extraction, retropulse and parasitic studies, shaped-pulse amplification, and the effects of modifications to the optical system. Planned system improvements and future experiments are also presented.

1. Introduction

As a prototype system, the objectives of the Aurora KrF/ICF laser facility have been twofold: to conduct laser physics and technology experiments important for future laser system development and to conduct target physics experiments relevant to weapons and ICF applications.

Typically a 1 nsec pulse from the Aurora front end is split into 96 beams which are angularly and temporally multiplexed to produce a 480 nsec pulse train for amplification by four KrF laser amplifiers. In the present system configuration half (48) of the amplified pulses are demultiplexed using different optical path lengths and delivered simultaneously to target. The other 48 beams were used for diagnostic purposes and related laser experiments.

The work done at Aurora may be divided into two main categories: laser physics experiments and the development of target physics capabilities. Several key issues have been addressed including the energy extraction from the Large Aperture Module (LAM), amplifier small-signal gain, shaped-pulse propagation through the amplifier chain, and the retropulse and parasitic problem. Target physics capabilities brought online include X-ray conversion efficiency measurements, encircled energy determination, and observation of shock breakout through selected targets.

Performance parameters (including optical pulse length and shape, energy delivered to target, and size of the focused spot) will be discussed. Planned system upgrades and potential future improvements are also presented.

2. System

Angular multiplexing forms the conceptually simple basis of the Aurora laser system. Basically, a short front-end pulse is replicated 96 times. The resulting pulses are temporally stacked one after another sequentially and amplified. The pulses are so stacked in order to efficiently make use of the long pumping times of the electron-beam amplifiers (typically 500 - 700 nsec). In order to have all the pulses arrive at the target plane simultaneously, the pulsetrain must be decoded using different path lengths to remove the time delays; the first pulses through the amplifiers require the longest path in the decoder to target. A schematic diagram of the Aurora system is shown in Figure 1. Only 48 beams are taken to target.

The front-end pulse of appropriate shape and bandwidth is replicated and amplified through a series of encoders and 4 amplifiers. The double pass Large Aperture Module (LAM) amplifier, with an aperture of 1 m^2, serves as the final stage before decoding to target. Descriptions of the front end, the four KrF laser amplifiers, the optical system, and the beam diagnostics have been published elsewhere.[1,2]

To date Aurora has demonstrated the following performance: 48 beams available to target; 1 - 20 nsec variable pulseshape; 600 µm spot diameter; 1300 J delivered energy; 40 cm^{-1} bandwidth; and up to 7 full system target shots per day.

3. Laser Physics Experiments

In addition to typical system support (characterization, analysis, and optimization), the laser physics program has two other goals: to generate an extensive data base in order to refine the kinetics code and to facilitate the design of larger KrF systems; and to investigate fundamental KrF laser physics, such as pulse shaping effects through the amplifier chain. Particular topics related to the former goal will be described below. Pulse shaping will be discussed in some detail in a companion paper to be given at this conference.[3]

The amplifier of primary interest is the LAM. Its size was chosen to address issues associated with the scaling of these devices to higher energy and lower cost. It is electron-beam pumped from two sides. Due to its large physical size, amplified spontaneous emission (ASE) could reduce energy extraction. ASE modeling codes for the LAM (with small-signal gain g_0, absorption α, and wall reflectivity as parameters) predict that ASE lowers the measured small-signal gain and energy extraction efficiency by 20%, confirmed by energy extraction measurements. In another experiment the LAM sidelight intensity was absolutely measured and agrees well with ASE code calculations with 20% wall reflectivity as shown in Figure 2.

Small-signal gain measurements of the Preamplifier (PA) and the Intermediate Amplifier (IA) were performed this past year. Small-signal gain as a function of pressure, Marx charge voltage, probe position, and active gain length was studied. Figure 3 shows that, for the PA, the small-signal gain increases as the gain length decreases, possibly indicating ASE loss. The gain length was reduced by blocking part of the electron-beam with thick copper sheets. This work was done as an effort to characterize and reduce the retropulse and parasitic problems encountered in the centered optical system. The gain length was then set at a safe level. A beam "gobbler" was also laid in the bottom of the the PA cavity to spoil possible parasitics.

Experiments were also performed to study the propagation of shaped pulses through the Aurora amplifier chain.[3] Scaling studies indicate that adding a tailored prepulse to the main driver pulse may substantially reduce the energy required to drive an ICF target. In general the pulse had a variable energy toe 5 - 15 nsec before the main 1 nsec spike. The contrast ratio (main-pulse height to toe) was varied from 10 to over 100. Faithful replication of 4 overlapped pulses in the target plane was demonstrated at LAM light levels.

4. Target Physics Capabilities

Target physics work was carried out the past year to qualify the system's performance at the target plane. Electric field strengths within the confines of a highly focused, high-energy multi-beam overlap at the target plane are such that the beam spot size and temporal profile are determined by observing the emitted X-rays. Several diagnostics are operational and available for target physics experiments. These include a holographic probe for plasma density measurements, X-ray sensitive streak cameras, a 100 psec gated X-ray imaging system, X-ray pinhole cameras, and an X-ray spectrometer (multiflex).

In order to better define the laser's performance, several experiments, which included work on X-ray conversion efficiency, encircled energy measurements, and shock breakthrough on a planar target, were undertaken. When the renovation described below is complete, these experiments will be revisited.

In addition, a stand-alone backlighter is being installed for target physics experiments. The Chroma glass laser previously located at KMS Fusion has been transported to Aurora. A new front end and control system will be added to the disk amplifier system. At KMS the system had demonstrated delivery of two 100 psec, 60 J pulses in the green (527 nm) of 10 - 15 X diffraction limit beam quality. This specification will be used as a starting point at Los Alamos.

5. System Improvements

Several system improvements are currently in progress at Aurora. The major goal is to deliver greater laser intensity to the target plane with better reliability. Greater intensity can be achieved by increasing the beam energy or by decreasing the spot size. In the past Aurora has delivered over 1000 J to target. Its pulse width has been adjustable from 1 - 20 nsec. Typical overlapped spot sizes were 600 µm using manual alignment to target. These parameters gave peak target irradiances of over 100 TW/cm^2.

System reliability has been another priority at Aurora. The Aurora amplifiers have been fired a total of 1489 times for a variety of different experiments this past fiscal year.

Among the improvements currently in progress are optical upgrades (especially with the centered optical system), a rebuilding of the system's pulsed power, and installing a new computer control system.

A new drive system for the LAM mirror mount is currently being tested. Because the old stepper-motor generated severe heat gradients in the amplifier box, the new driver is piezoelectric and will add a negligible heat load to the laser gas mix. Previously, obtaining good beam quality on target required prolonged mixing of the laser gas.

New optics are being installed throughout the optical train. Complete metrology, including damage testing, is being done on all components to assure that they meet specifications. Several optics had been damaged, in part due to a retropulse and parasitic problem in the PA and IA areas. The refractive optics are anti-reflective coated and those with lower damage thresholds had been burned by the retropulses. To preserve the optics the PA gain had to be turned down.

Modeling has shown that the major contributor to the retropulse problem is the IA exit lens and experimental evidence supports this conclusion. A temporary fix will be to tilt this lens and accept a slight penalty in spot size. Figure 4 shows raytracing calculations for two cases of IA exit lens tilt. The left side shows beamlet size for three typical beamlets with a 1.8° lens tilt. The beamlet size is compared to an effective 400 µm spot diameter circle in the target plane drawn on the figure. A 20 wave correction to the mirror after the IA exit lens was added in the calculation and shows that the beamlet size is reduced by a factor of 2 with the same lens tilt. Note that the scale size of the circle is halved. To more fully drive all the amplifiers, the final splitter in the 8-fold encoding section (where 48 beams are replicated to give 96 beams) has been removed. Using only the first 48 beams demands a smaller tilt of the IA exit lens resulting in less degradation of the spot size.

The ultimate solution to this retropulse problem is to provide time-of-flight isolation between the PA and the IA. Conceptual designs for this have been developed. High damage threshold coatings will also help avoid this problem. Eventually the PA and IA gains will be safely increased, allowing the LAM to be more fully loaded for maximum energy extraction.

A computer controlled automatic alignment station at the target chamber has been implemented. After a rough alignment the computer aligns and overlaps the 48 beams in only five minutes. Finally the tunnel air conditioning system has also been refurbished to provide a more uniform temperature which reduces index gradients throughout the optical beampath.

7. Conclusion

With the above improvements, Aurora is expected to realize >1 KJ in a 300 μm spot in the target plane. The pulse length already has been shown to be variable from 1 - 20 nsec. Bandwidths will also be variable from 1 - 150 cm^{-1}. Pulse shaping has been demonstrated with two step contrast ratios up to 100:1. The system should be reliable enough to average 5 full system shots per week with a significantly reduced operations and maintenance crew. The successful demonstrations of multiplexed alignment systems and scalable amplifiers have shown that the basic components of KrF technology can be extended to future systems with low risk and reduced cost. In addition to conducting target physics experiments, Aurora will be used as a testbed supporting future KrF technologies.

8. Acknowledgments

This work was funded by the U. S. Department of Energy, Division of Inertial Fusion. The list of over 50 staff members and technicians on the Aurora project is too long to publish within this report, but their hard work and dedication is gratefully acknowledged.

9. References

1. "Configuration and Performance of the Los Alamos Aurora KrF/ICF Laser System", T. P. Turner, J. E. Jones, S. J. Czuchlewski, R. G. Watt, S. J. Thomas, D. A. Netz, C. R. Tallman, J. M. Mack, and J. F. Figueira, SPIE Vol. 1225 High-Power Gas Lasers (1990), P. V. Avizonis, C. Freed, J. J. Kim, and F. K. Tittel eds., pp. 23-33.

2. "Inertial Confinement Fusion at Los Alamos, Progress Since 1985", Los Alamos National Laboratory Report LA-UR-89-2675, D. C. Cartwright ed., vol. I, Sept. 1989.

3. "Temporal Pulse-Shaping on the Aurora KrF Laser", S. Czuchlewski, T. Turner, J. Oertel, W. Leland, N. Kurnit, R. Watt, J. Mack, S. Coggeshall, and D. Hanson, Lasers '90, San Diego, CA, Dec. 10-14, 1990.

10. Figures

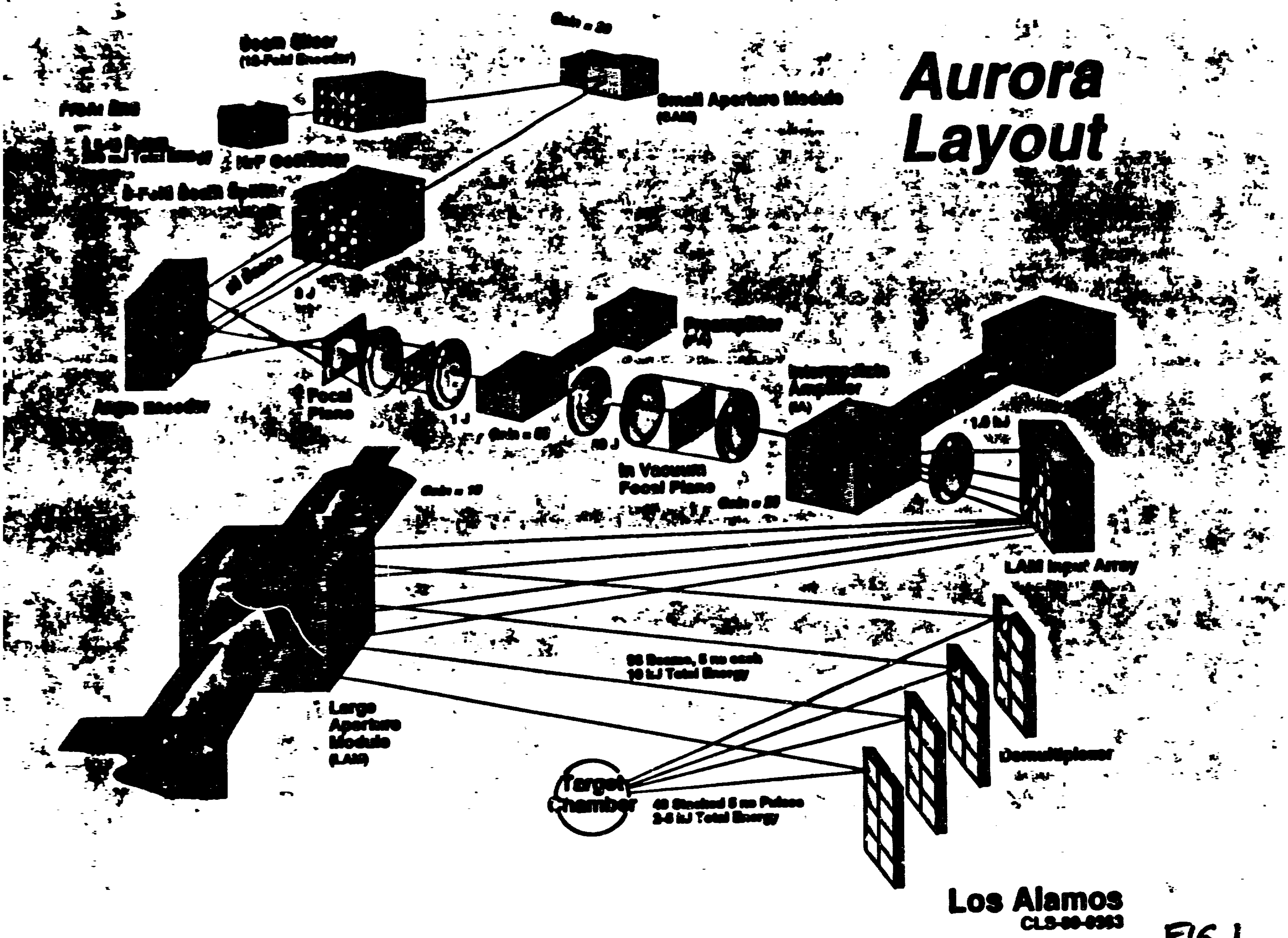
Figure 1: Schematic of the Aurora laser. The front end produces a pulse which is replicated 96 times, 48 beams of which go to target. The pulse train passes through 4 amplifiers and is decoded before hitting the target. Kilojoule level energy is available at the target plane.

Figure 2: LAM sidelight radiance as a function of the gain length product $(g - \alpha)L$. Two data sets are calculated: 0 and 20% wall reflectivity, respectively.

Figure 3: PA small-signal gain as a function of gain length. Because ASE is less important role, the gain length decreases, the measured small-signal gain increases.

Figure 4: Raytracing calculations for three typical beamlets demonstrating the effect of the IA exit lens tilt

of 1.8°. The lefthand case shows the results for the tilt alone. The righthand case adds a 20 wave correction to the turning mirror after the lens. The circle shows the effective spot diameter in the target plane. Note that the scales for the two cases are different by a factor of two; the 20 wave correction puts a smaller beamlet on target.



Aurora
Layout
Small Aperture Module
(SAM)
KrF Oscillator
Focal
Plane
1 J
Preamplifier
(PA)
Intermediate
Amplifier
(IA)
In Vacuum
Focal Plane
Gain = 10
LAM Input Array
96 Beams, 5 ns each
10 kJ Total Energy
Large
Aperture
Module
(LAM)
Target
Chamber
48 Stacked 5 ns Pulses
Demultiplexer
Los Alamos

FIG 1

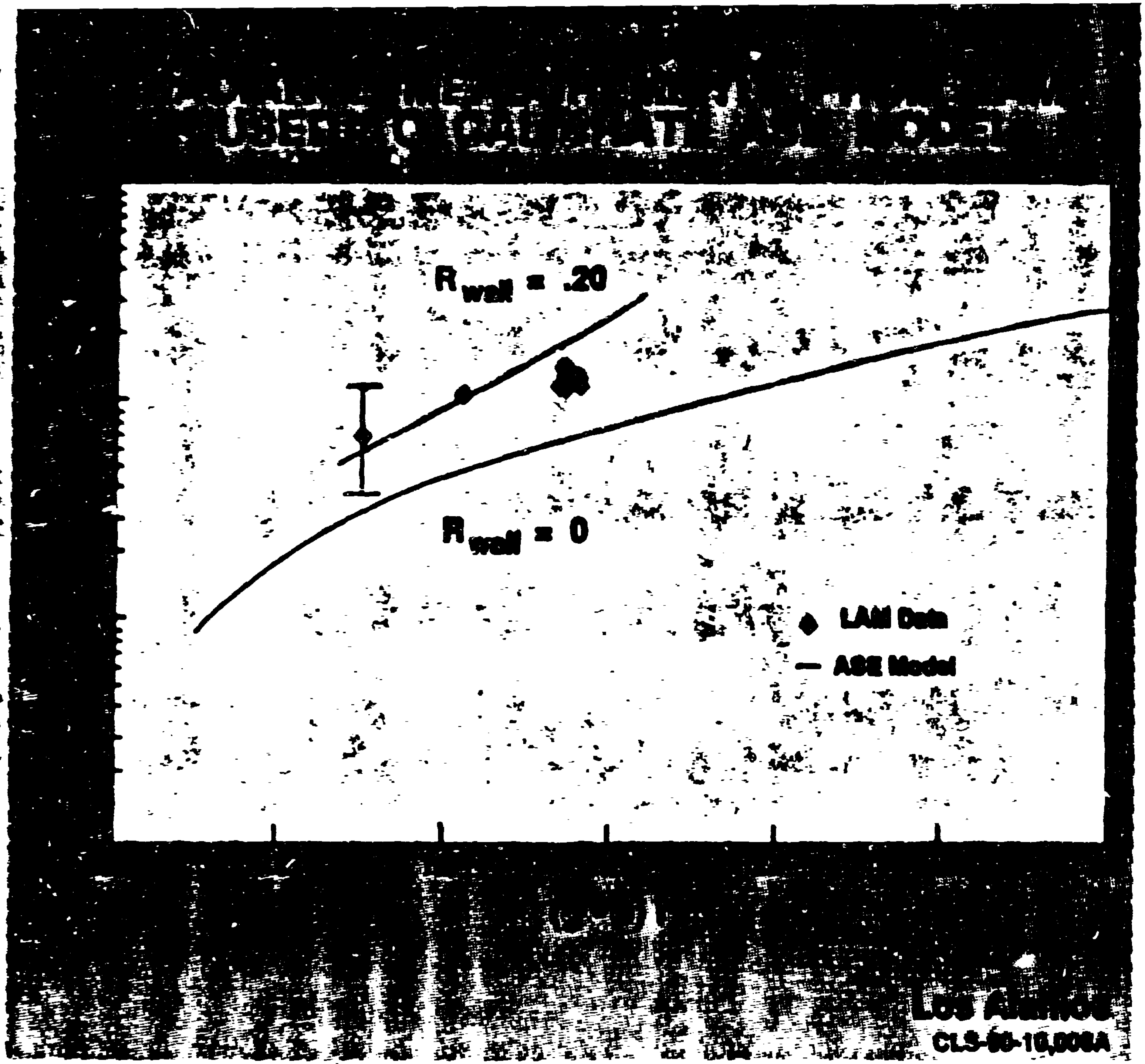


FIG 2

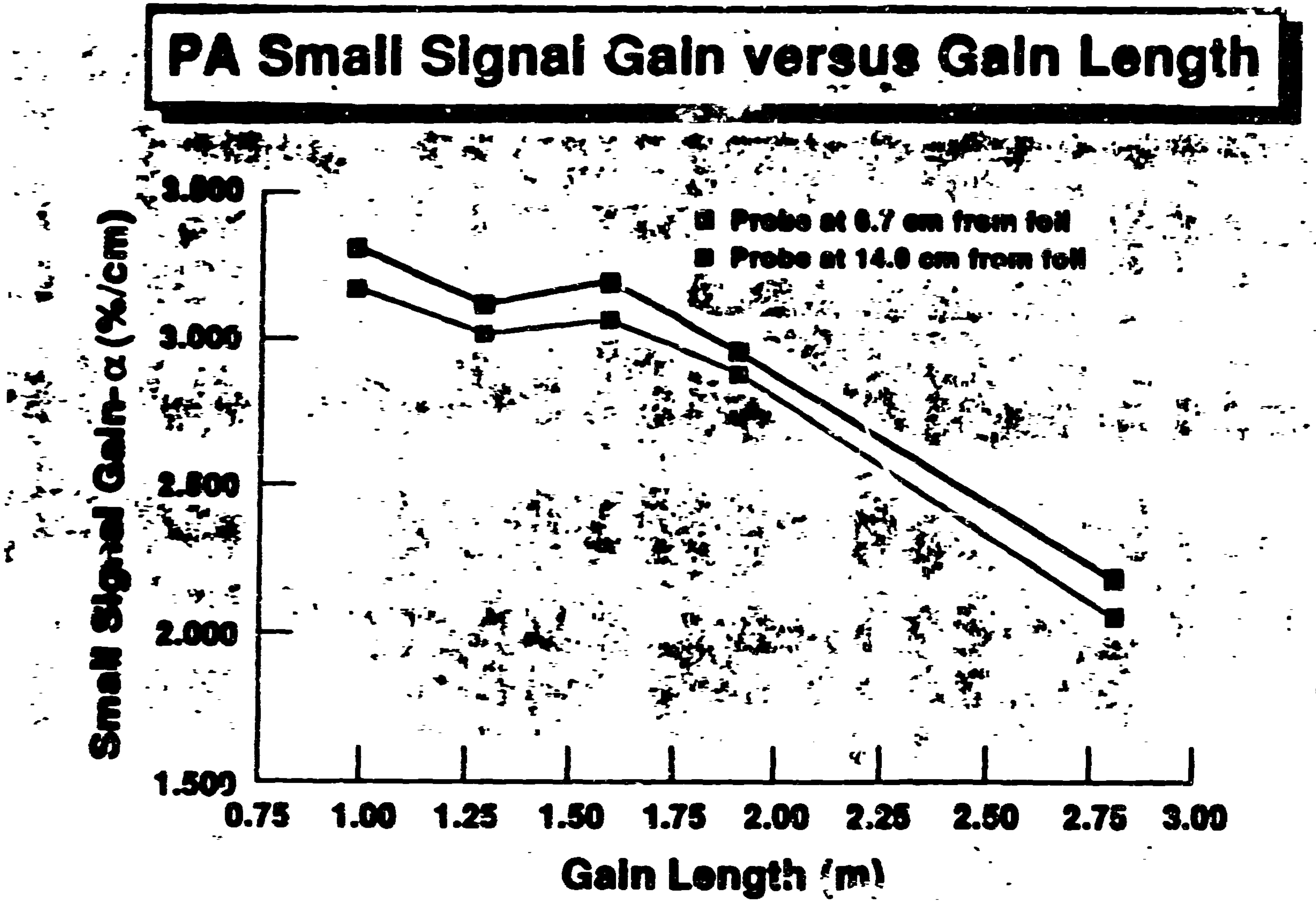


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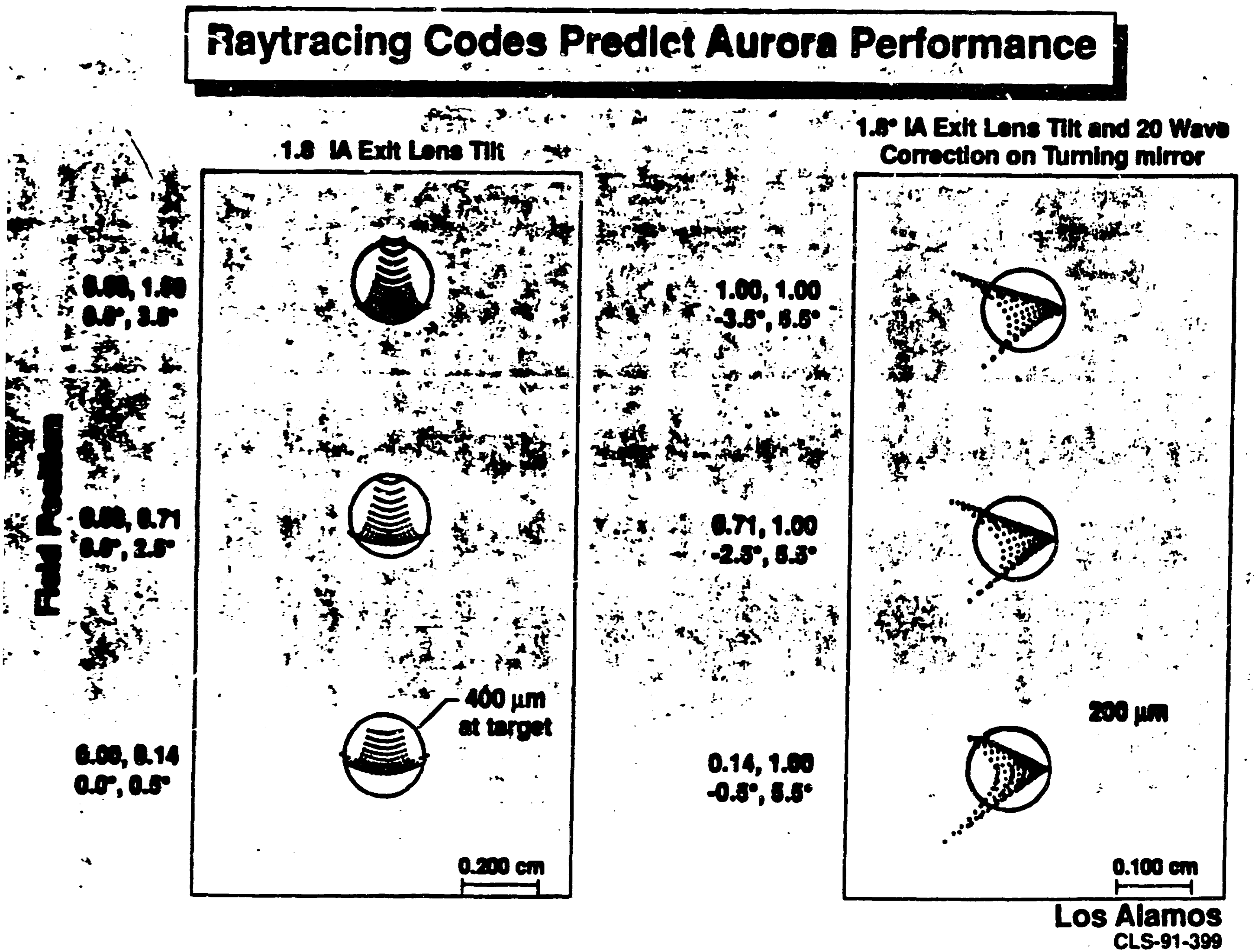
FIG 3



Raytracing Codes Predict Aurora Performance
1.8 IA Exit Lens Tilt
1.8° IA Exit Lens Tilt and 20 Wave
Correction on Turning mirror
1.00, 1.00
-3.5°, 5.5°
0.71, 1.00
-2.5°, 5.5°
0.14, 1.00
-0.5°, 5.5°
0.0°, 0.5°
400 µm
at target
200 µm
0.200 cm
0.100 cm
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FIG 4