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EARLY-TIME MEASUREMENTS OF LASER-PLASMA CONDITIONS IN OMEGA-UPGRADE ICF TARGETS

Final Report
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Final Report

EARLY-TIME MEASUREMENTS OF LASER-PLASMA CONDITIONS IN OMEGA-UPGRADE ICF TARGETS

All of the experimental results from OMEGA shots described here are from CY-1998 experiments under an (extended) FY-98 grant. This research involves fielding at LLE our two flat-field euv spectrographs in the 30-250 Å range, mainly utilizing on one of them a gated stripline microchannel plate as a time-resolved detector, with photographic recording.

The experimental layout for the 1998 experiments is shown in Fig. 1. All but one of the 60 beams from OMEGA, operating at 20 kJ of energy in a 1 ns pulse, were focused onto a spherical target of diameter 940 μm, for an irradiance of ~$2x10^{14}$ W/cm^2. Beam smoothing was provided by a combination of spectral dispersion (SSD) as well as distributed phase plates (DPP's). The plastic microballoon targets of 20-μm wall thickness were filled with neon to a pressure of 10 atm, including a 10% admixture of argon as a tracer. A sealant coating of aluminum [0.03 μm (300-Å) thick in May 1998 (reduced to 0.0125-μm (125-Å) in October 1998] was followed by an outer coating of Mg of thickness 2 μm.

During the week beginning May 3, 1998, we obtained 24 data shots over 4 days, and fielded both our time-gated extreme ultraviolet (euv) spectrograph mounted external to the target chamber, as well as our newly-constructed TIM-mounted euv spectrograph mounted closer to the target with time-integrated photographic recording on a trial basis. We also had available the LLE/LLNL streak x-ray spectrograph and x-ray imaging cameras. In this series, the first two shots appeared from the x-ray streak spectra to be "normal" in the sense that the spectral line emissions from the two coatings sequenced beginning with magnesium followed by aluminum as the coatings were vaporized. This is illustrated in Fig. 2. It was observed that the emission during collapse appeared to be low compared to that from previous experiments (and see Fig. 5 below).

Unfortunately, on the following shots in this campaign it became increasingly apparent that conditions had changed radically, and later analyses showed that x-ray spectra lines from the deep aluminum undercoating appeared initially along with weak magnesium lines, indicating a premature vaporization of the magnesium heavier top layer (Fig. 3), as compared with Fig. 2 above. This was also confirmed in our analysis of the time-gated euv data, which showed emission as early as 10 ns prior to laser initialization (Fig. 4). An important point is that such early "prepulse" signals were not observed on the first two "normal" shots as described above. Hence, whatever led to the prepulse occurred suddenly and continued throughout our May 1998 campaign. The spectrum at these early times included magnesium lines, along with a continuum at a level of approximately 1% of that at the time of the laser peak. Spectral signatures during this "prepulse" phase were sufficiently distinct from those at later times to rule out an afterpulse effect from the pulsed MCP detector. A complete description of the prepulse measurement is available upon request, and was also presented in collaboration with LLE personnel at the November 1998 meeting of the APS Division of Plasma Physics in New Orleans [1]. These measurements represented the first indication of a prepulse from target measurements. It serves to emphasize that a value of the NLUF program with the possibility of independent participation resulting in new observations relating to OMEGA operations. The premature prepulse effect in the May campaign negated any possibility of deriving a meaningful temporal history of the magnesium euv spectral lines during the heating phase of the main pulse. That, however, did indeed become possible in the following series, as described next.

Our second campaign in 1998 occurred during the week beginning October 18, 1998 and consisted of 21 data shots over two extended (12-hour) days following setup. For this series we again used our externally-mounted euv spectrograph with time resolution and the x-ray streak spectrograph and imaging cameras. (We did not field the TIM mounted spectrograph on this series; we had not had the resources to convert it to MCP operation.) Much to our relief, it was immediately evident from the x-ray streak spectra obtained that significant ablation of the magnesium coatings by a (presumed) prepulse was not present, as it had been in the May campaign. More specifically, the emission from the aluminum undercoating followed temporally that from the outer magnesium layer. Also, the x-ray continuum emission at the time of the main compression was more pronounced, indicating a more efficient compression. A typical streak spectrum is shown in Fig. 5. Notice the more intense continuum emission during the main collapse at 2.4-2.8 ns, compared to that in Figs. 2 and 3 which was obtained in the May 1998 campaign. This indicates that the problem that existed in May also affected the efficiency of collapse at that time.

The euv spectroscopic results from the October 1998 campaign of Mg X, XI and XII spectra from n=3 to n=2 transitions are plotted in Fig. 6 versus time as photographic densities corrected for variations in spectrograph parameters between shots. Here the t=0 point is set somewhat arbitrarily to coincide with the fast rise of the emission. The data plotted represent a composite between the three most sensitive striplines, delayed relative to each other, for a number of shots. The spectral-line intensities were measured from the continuum, which rises during the collapse phase. Further corrections will to be applied as necessary for any non-linearities associated with the detection system, to be determined independently from multiple exposure data at the University of Maryland. The intended emphasis was on the early portion of the event while the laser intensity is rising to a peak. The overall history agrees with that from the x-ray data shown in Fig. 5, i.e., the peak period of emission being in the first 1.5 ns. It is anticipated that these data will soon be compared to numerical modeling performed at LLE by Drs. Jacques Delettrez and Reuben Epstein. By varying the temperature for a best fit, we expect to arrive at an electron temperture, as well as an electron density that can be compared with our estimates from Stark broadening of both x-ray as well as euv spectral lines. Evidence for the validity of Stark broadening for both sets of lines comes from the observation of significant (~X3) narrowing (including the Mg XII, Balmer-α, n=3 to n=2 transition line in the euv spectral region) at late times when it is expected that Doppler broadening will dominate.

Besides euv spectral lines from the n=3 to n=2 transitions in magnesium, resonance lines from carbon (and oxygen) were recorded at early times, presumably originating from the stalk supporting the microballoon targets, which is inevitably irradiated by some of the 59 beams used. Also, an Al XIII Balmer-α feature was observed during the period of the laser pulse at a much lower level than that for magnesium, being from a very thin layer (125-Å thick, even thinner than the 300-Å thick layer used in the May 1998 experiments). Also appearing at a low level and with some overlap with others were spectral lines from neon and argon from the gaseous filling. These occurred at late times, extending to at least 10 ns, i.e., well after collapse and during final expansion.

Those lines definitely identified were from n=3 to n=2 transitions in the spectra of hydrogenic Ne X and in Ar IX-XIII, all with ionization potentials in the 420-1360 eV range. In fact, the normally intense spectral line from a 3d-2p "resonance" transition in Li-like Ne VIII (ionization potential =239 eV) was surprisingly weak. This indicates that even at late times the ionization stage and "temperature" are high in the "frozen-in" state during expansion and recombination. As a further check, the continuum intensity was also found to agree with the x-ray streak spectral history at times extending into the collapse phase.

In this October 1998 campaign, we continued to measure a prepulse in the euv emission at a level of about 1/4 that found in the May 1998 campaign, still as early as 10 ns prior to the beginning of the main laser pulse. However, in this case, the euv spectral lines originated mostly carbon (and oxygen) and continuum. This indicates that the magnesium overcoating was not significantly removed in this series, which is consistent with the more "normal" x-ray (and euv) spectral sequencing described above. Although the source of such a prepulse remains unexplained, more direct evidence was found during this October 1998 campaign from photodiode measurements on the incoming laser beam at the chamber entrance, precipitating an intention to further investigate and eliminate any prepulse in anticipation of the possibility that it could unexpectedly arise again to the harmful level present in May 1998.

We were able to obtain a series of shots on the TRIDENT laser facility at the Los Alamos National Laboratory in September 1998. Using two opposing beams (at 0.53 μm wavelength) onto slab targets, we recorded, using a time-gated x-ray crystal spectrograph, spectra from Mg, Al and Si. Digital recording from a CCD camera was used. We also were able to achieve spatial resolution along a direction normal to the target surface. With 170 J per beam in a 1 ns Gaussian pulse, focused to a diameter of 500 μm, we obtained a typical target irradiance of 9×10^{13} W/cm^2 (for 100% absorption). We observed line radiation from resonance transitions in hydrogenic and helium-like ionic species, as well as innershell satellite lines in the next lower species. We also observed K_α type transitions at the target surface, which arose from the first few ionization species. Thomson scattering diagnostics also provided us with a temperature and density value useful in numerical modeling of the data.

Typical results are indicated in the spectral scans presented in Figs. 7 and 8 for magnesium and silicon, respectively. In the case of silicon, notable features include unusually intense (relative to nearby lines) well-displaced satellite lines arising from $2s^2$-$1s2p$ and $1s2s^2$-$1s^22p$ transitions in He-like and Li-like ions, respectively, which involve a two-step process with one photon being emitted. They arise from interactions between the $2s^2$ and $2p^2$ configurations for the two cases. Various explanations for the apparent anomalous satellite intensities have been offered, including opacity in the radiative transfer of the more intense dipole lines. However, a complete explanation is still lacking. The experimental results, along with numerical modeling of the atomic processes and radiative transfer, have been accepted for publication [2].

From the scan for magnesium shown in Fig. 7, one sees the n-to-1 resonance spectral series for both H- and He-like ions merging with the continuum emission when $n=6$ to 7. From the Inglis-Teller relationship [3-5], an electron density can be derived. From the relative line intensities of the spectral series it is also possible to derive an electron temperature. Further analysis of the transition region from lines to continuum is planned, including modeling with the CRETIN code, courtesy of Lawrence Livermore Laboratory.

A very useful aspect of the (mostly) magnesium targets was our ability to reproduce irradiances as low as a few x 10^{12} W/cm^2 on two-sided layered planar targets consisting of 20-µm thick CH covered with 300-Å of Al and finally a 2-µm thick Mg coating, simulating the surfaces of the spherical targets used at LLE. We were able to demonstrate that Mg XI and XII x-ray spectral lines are produced at measureable intensities at such an irradiance. This was a point of question in our prepulse measurements at LLE in May 1998 described above, where spectral lines from such species were recorded prior to the main laser pulse.

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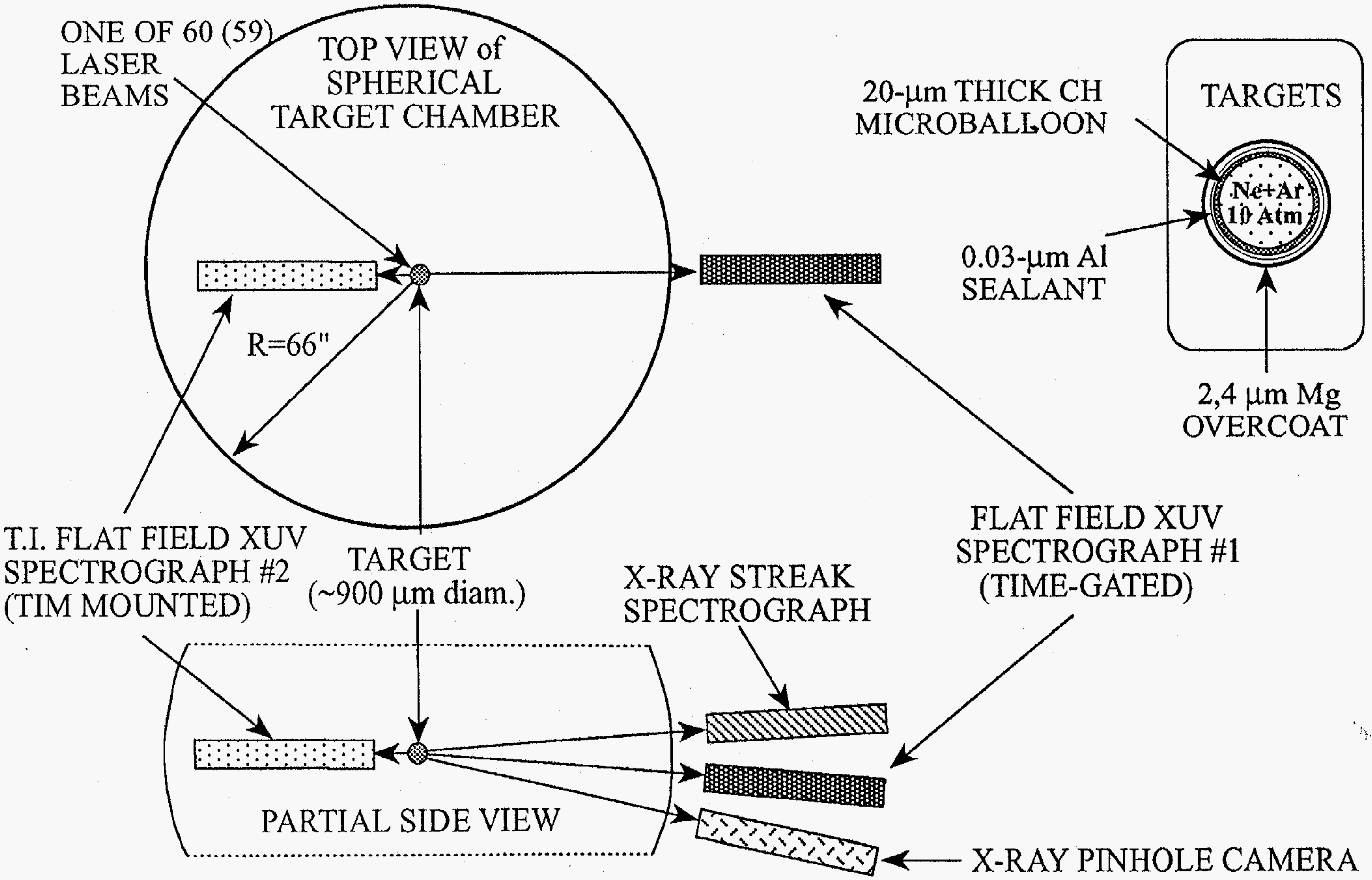
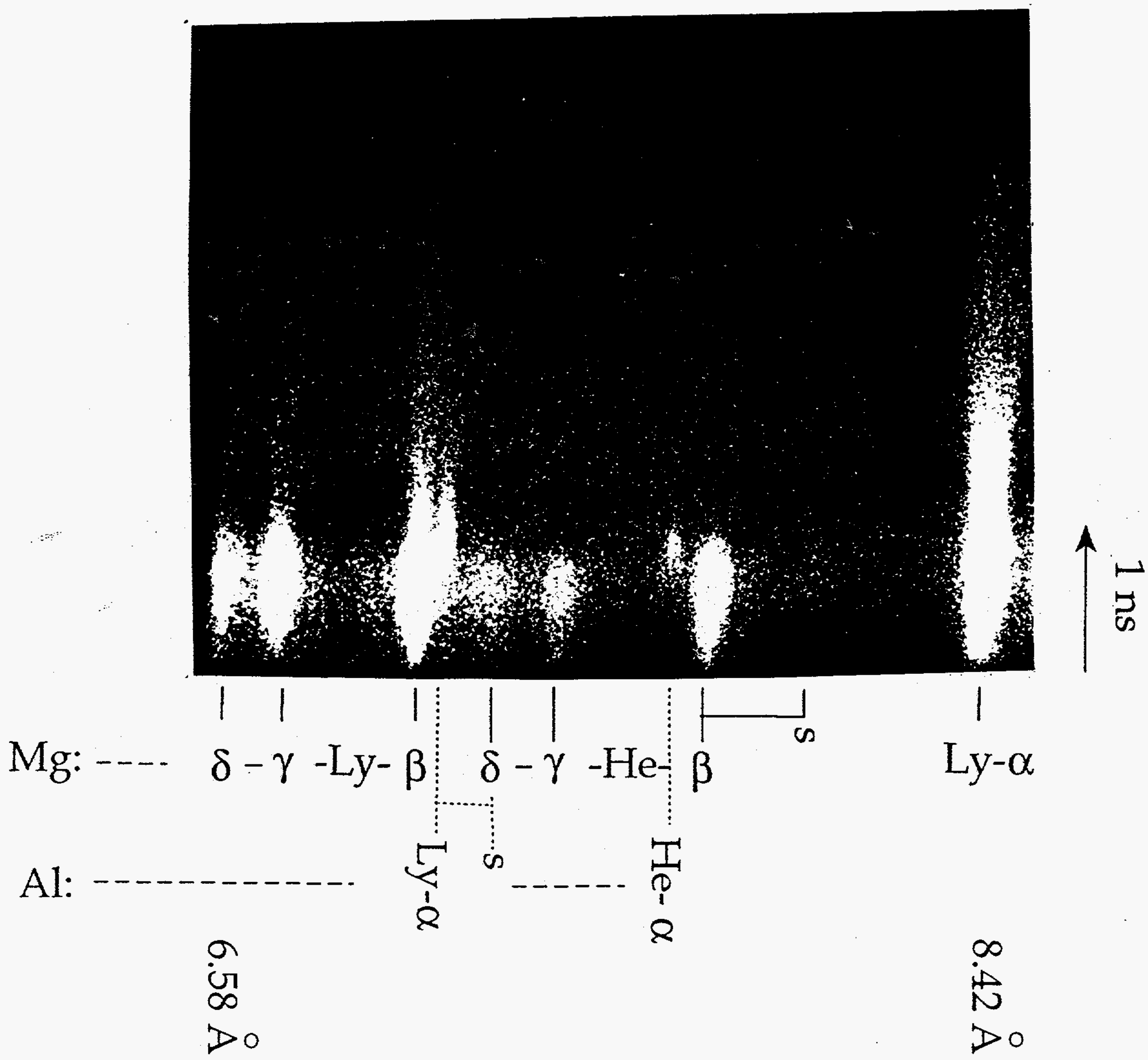
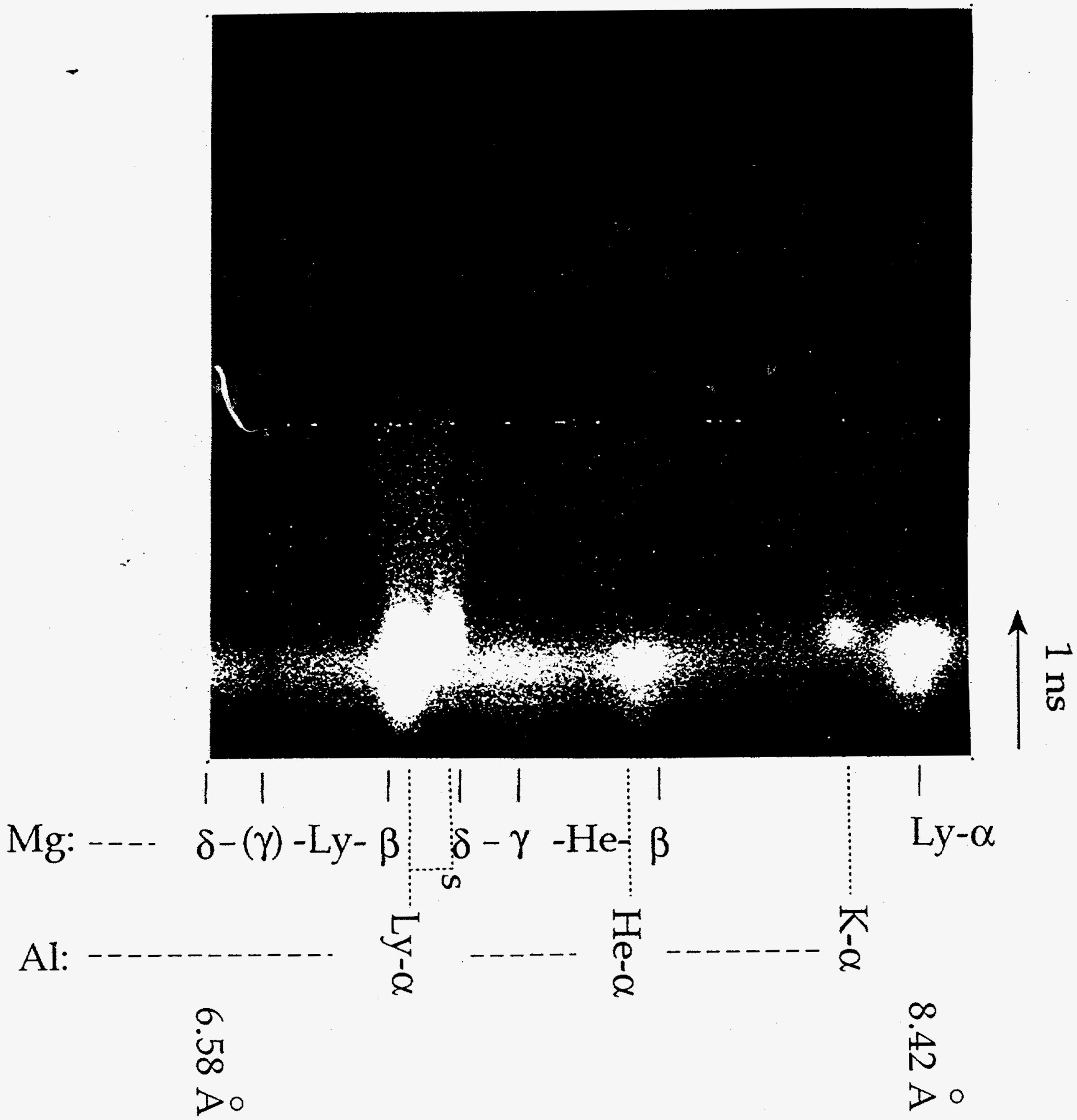


Fig. 1. Layout for 1998 experiments



Shot 12459

Fig. 2. "Normal" x-ray streak spectrum, without a prepulse.



Shot 12473

Fig. 3. X-ray streak spectrum in presence of prepulse.

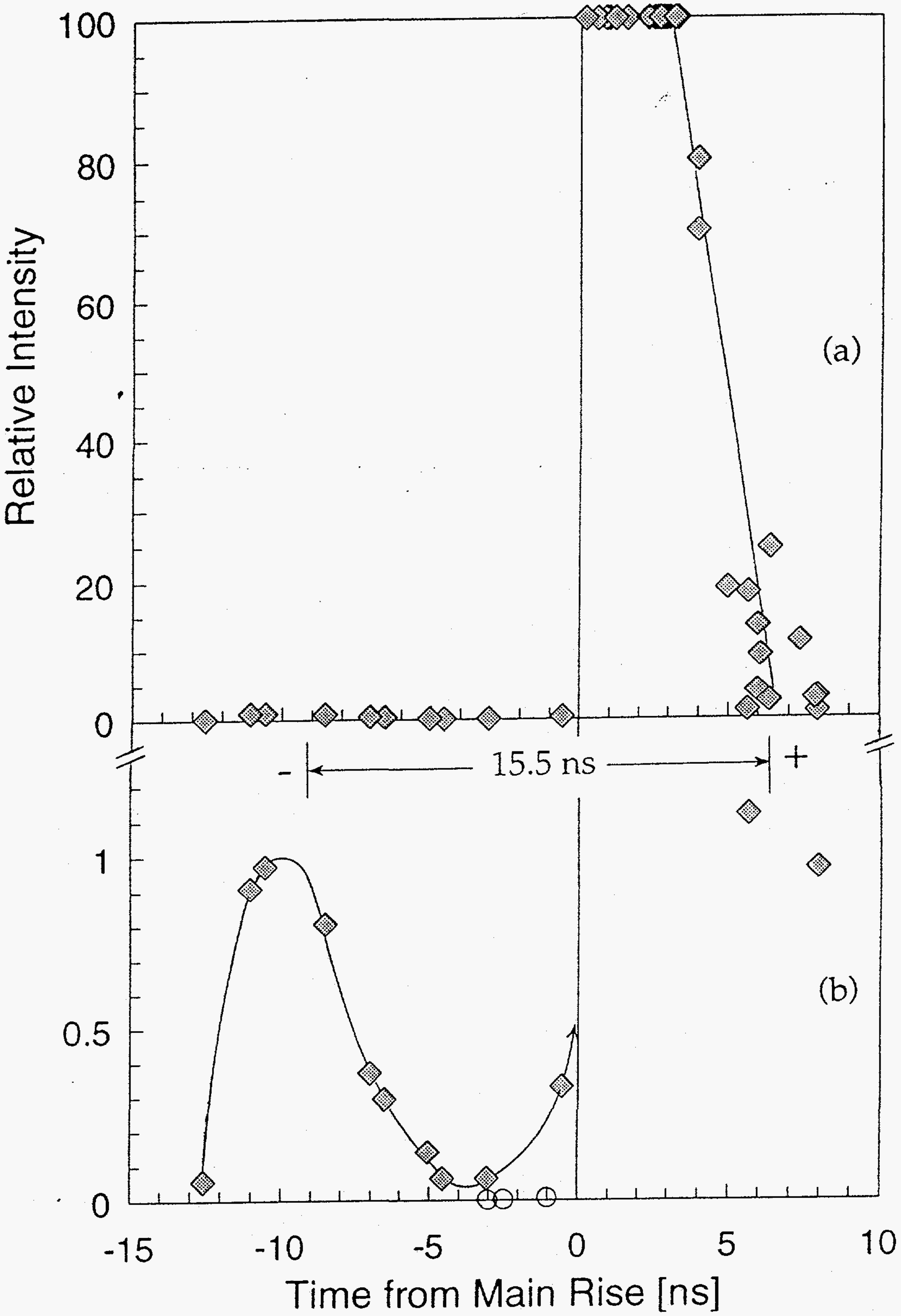


Fig. 4. Time-resolved euv data showing prepulse on expanded scale.

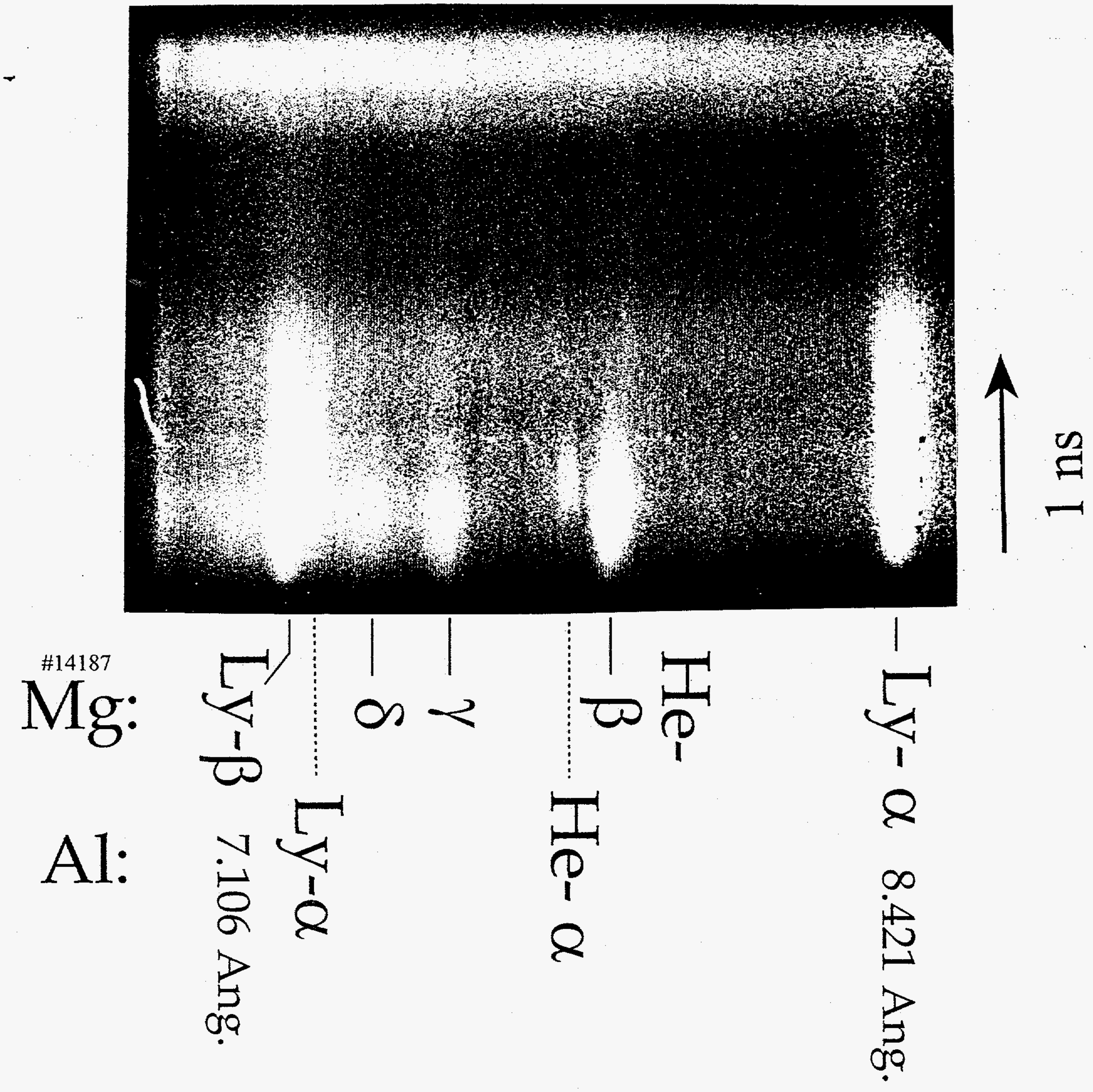


Fig. 5. "Normal" x-ray streak spectrum (10/98 run) with reduced prepulse.

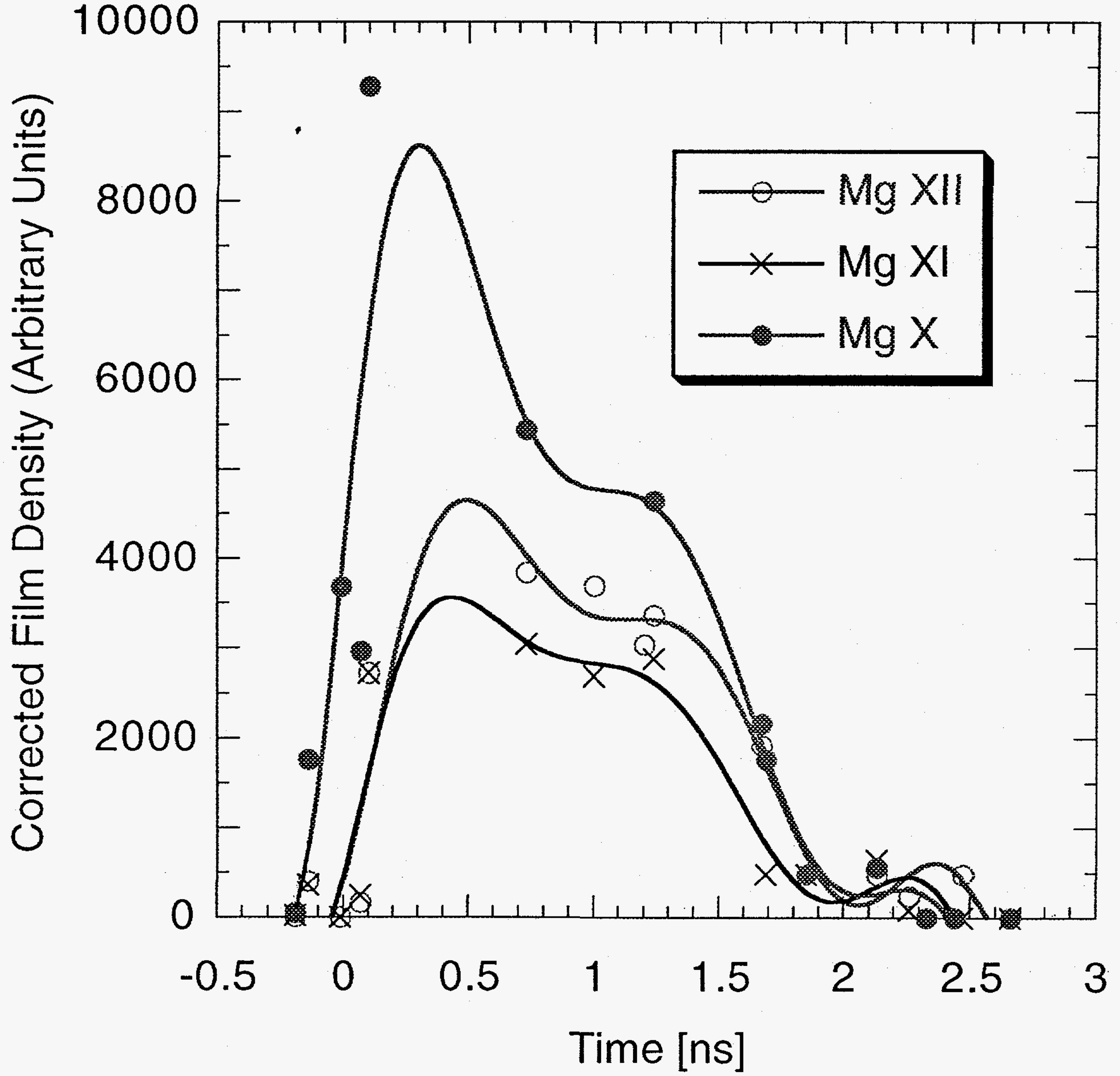


Fig. 6. Time history at early times from 10/98 euv spectral data.

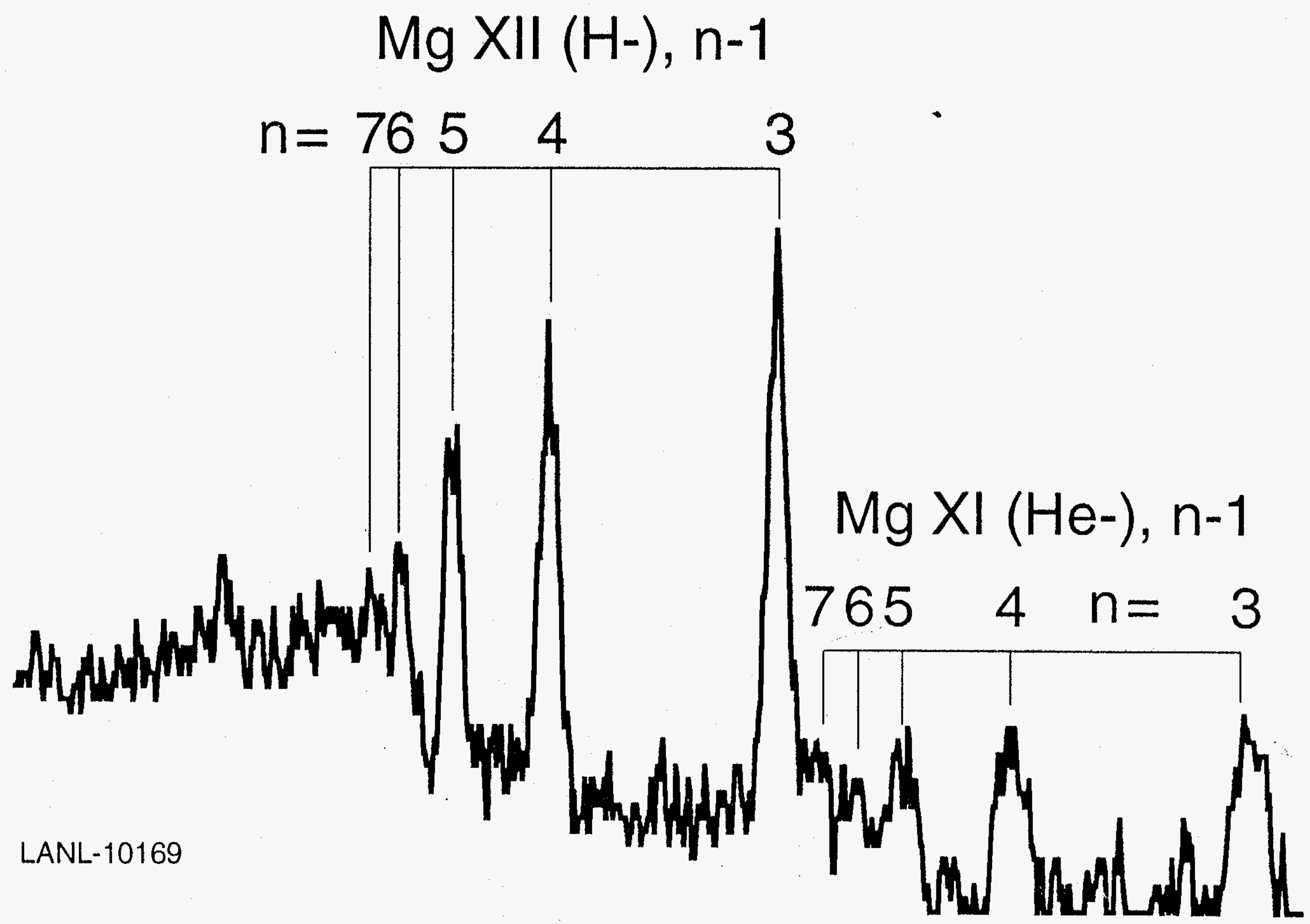


Fig. 7. Magnesium spectrum obtained with the TRIDENT laser at the Los Alamos National Laboratory.

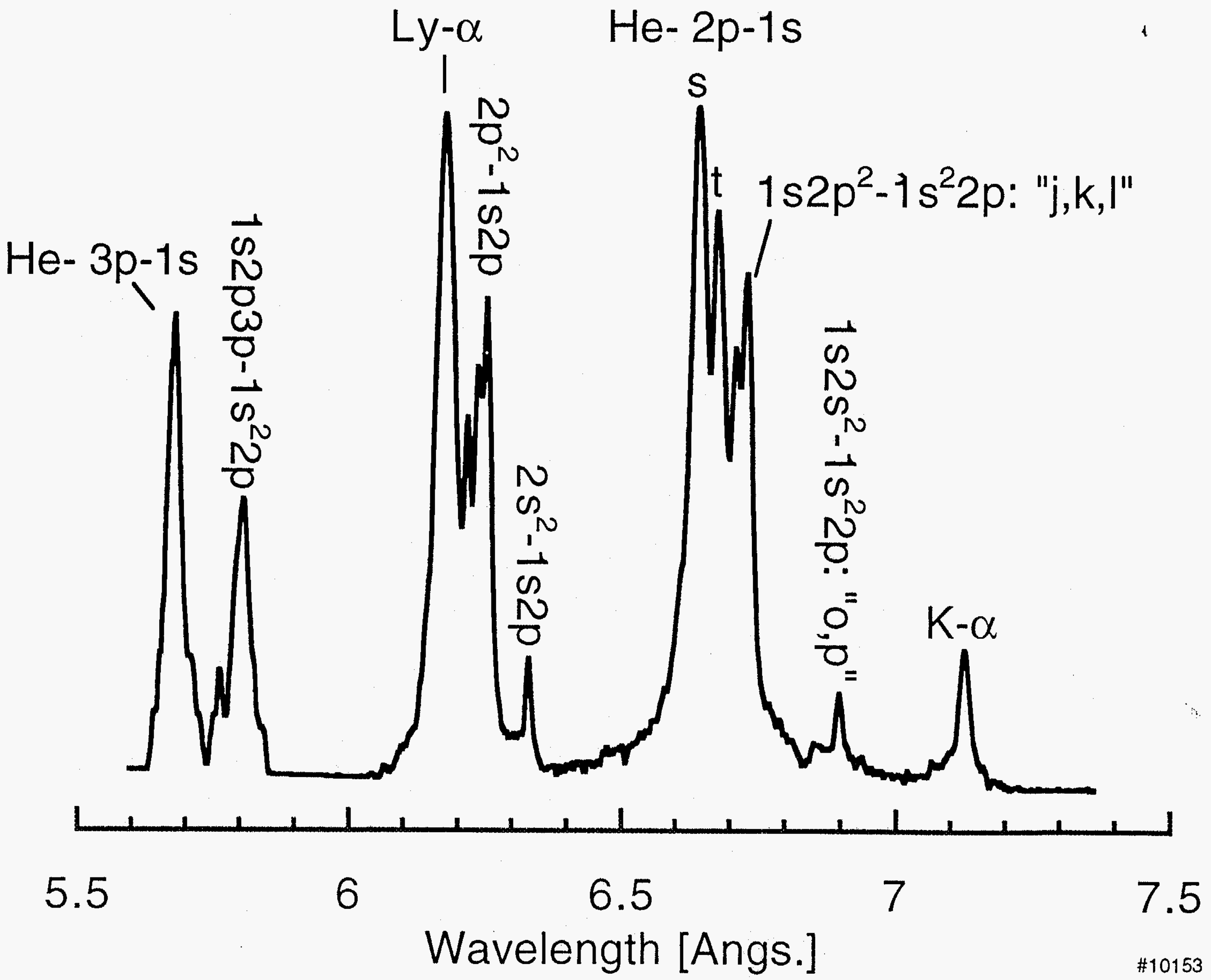


Fig. 8. Silicon spectrum obtained using the TRIDENT laser at Los Alamos National Laboratory.