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Time-resolved x-ray emission from laser-produced plasmas with timing fiducial

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High-temperature plasmas were produced by focusing 1·05 μm, 100 psec laser pulses onto Al layer targets at a mean irradiation of $3 \cdot 10^{13}$ Watt/cm^2. By means of simultaneous measurements of the thermal x-ray emission and the frequency-quadrupled laser pulse we observe a 20 ± 15 psec delay of the x-ray peak relative to the peak of the incident laser pulse. In addition, modulations on the trailing edge of the driving pulse appear strongly enhanced in the x-ray signature.

Measurements of the temporal evolution of the x-ray emission with a precise temporal reference to the driving pulse are of fundamental significance for laser fusion and x-ray laser research. The x-ray spectral signatures provide information about the nature of the laser light absorption and the transport of energy between different regions of the ablating plasma. To obtain such data optical and x-ray signals have to be recorded at the same time. Simultaneous measurements of the hard x-ray emission ($h\nu > 30$ keV) and the incident 1·06 μm laser pulse using the S1 cathode of an optical streak camera have been reported recently (Lerche & Phillips 1981). Corresponding measurements of the soft x-radiation, however, require different photocathodes for the two spectral regions. In one experiment the x-ray emission and the 0·35 μm laser light specularly reflected from the plasma were recorded with a hybrid photocathode (Marjoribanks *et al.* 1982). The reliability of the timing fiducial derived from the temporally varying reflective properties of an expanding laser-driven plasma may, however, be questioned. In another experiment the x-ray emission and the 1·05 μm laser pulse were recorded with separate streak cameras driven by a common ramp generator (Balmer *et al.* 1985).

In this letter we report an alternative approach. The soft x-ray emission from plasmas produced by 1·05 μm laser light and a frequency-quadrupled fraction of the laser pulse were simultaneously recorded with a single streak camera equipped with a specially designed hybrid cathode. The UV fiducial was introduced onto the photocathode along a separate path and thus represents a reliable reference for relating the x-ray signature to the peak of the driving pulse.

The experimental layout is shown in figure 1. The measurements were performed with 100 psec, 1·05 μm laser pulses, focused normally onto a 3000 Å layer of Al coated on a thick perspex slab target. The mean irradiation on target was about $3 \cdot 10^{13}$ Watt/cm^2 for an incident laser energy of typically 0·2 J. The x-ray streak camera was of a re-entrant design with the plane of the photocathode about 10 cm from the plasma. The home-made cathode consisted of a 220 Å layer of Au sputtered onto a 1 mm thick quartz substrate and a 1200 Å layer of CsI evaporated onto a 14·5 μm thick Be foil. A 14·5 μm Be foil between the plasma and the cathode served to block scattered UV radiation from reaching the UV section of the cathode. In this configuration, either section was opaque to radiation of the other section. The x-ray emission recorded by

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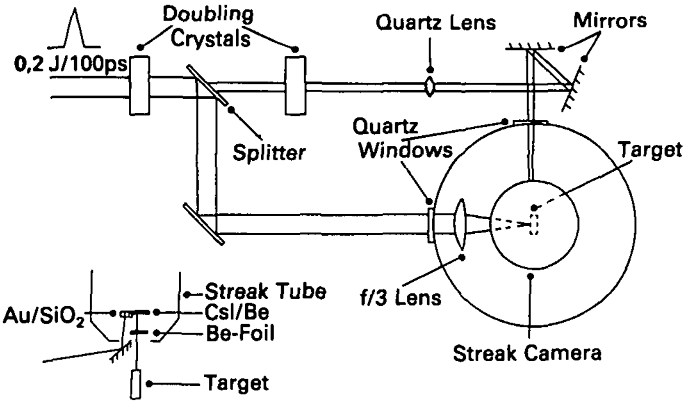

FIGURE 1. Experimental set-up.

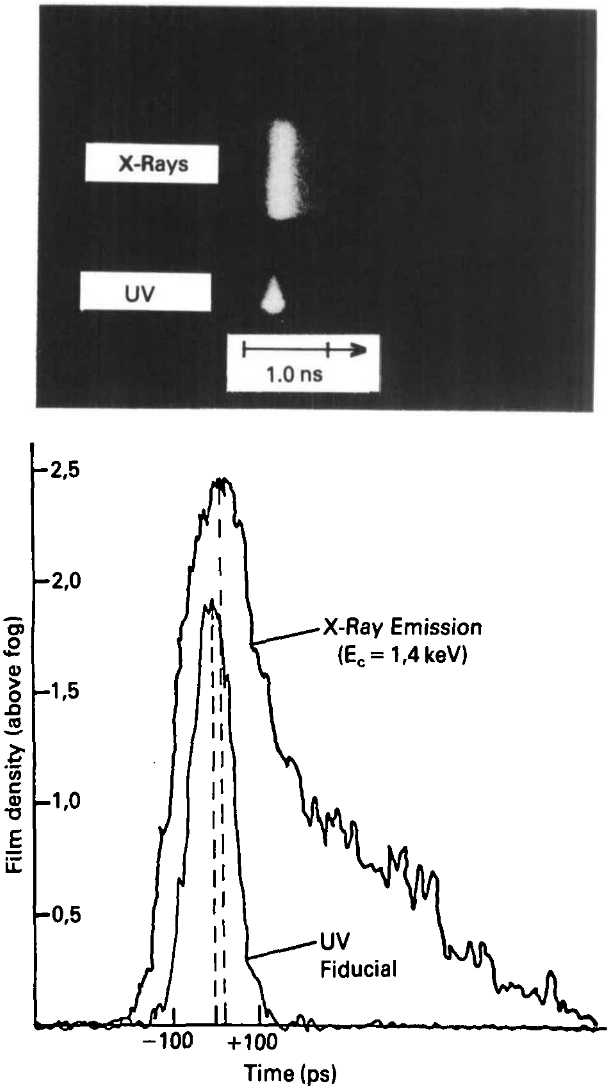

FIGURE 2. X-ray streak camera image of a temporally modulated laser pulse and microdensitometer traces.

the streak camera was thus composed of Al line emission and continuum radiation with an energy cut-off of about 1·4 keV.

The relative timing of the two signals was calibrated by running the fourth harmonic of the 1·05 μm Nd: Glass laser along both beam paths onto a Au-on-Quartz cathode. The quadrupling crystal was inserted in front of the beamsplitter, the focusing lens and the IR turning mirrors were removed and replaced by a quartz lens and Al mirrors, respectively. A UV turning mirror was installed at the exact position of the target. These changes in optical path length were taken into account for the absolute UV calibration. We found that the plasma x-ray history could be measured to within 15 psec relative to the peak of the driving pulse. The largest individual error was ±10 psec and resulted from the UV calibration, although the two beam paths were adjusted to minimize errors due to nonlinearities of the sweep speed and distortion of the intensifier. The measured sweep rate on the phosphor of the intensifier (Mullard 50/40) was 52 psec/mm with a linearity of better than 10%.

The streak data was recorded on calibrated Kodak Royal-X Pan film and analyzed

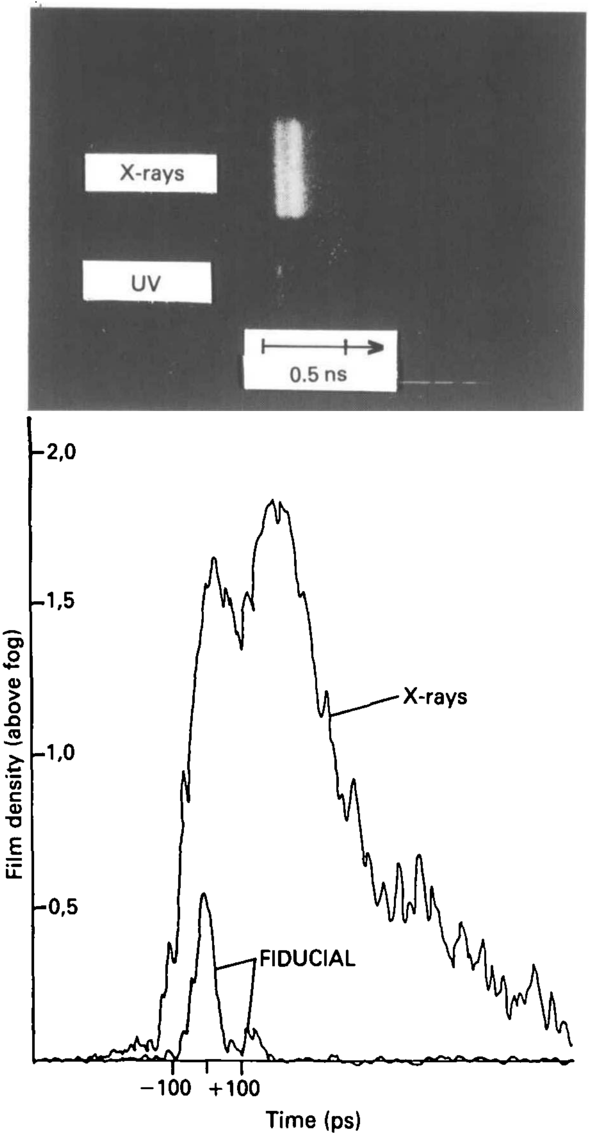

FIGURE 3. X-ray streak camera image and microdensitometer traces.

on a microdensitometer. The temporal evolution of the thermal x-ray emission, together with the UV fiducial signal is shown in figure 2. The zero on the time scale corresponds to the peak of the incident laser pulse. It can be seen that the x-ray emission peaks approximately 20 ± 15 psec after the peak of the UV pulse and exhibits a low-intensity tail below about 2% of the x-ray peak intensity. This loss of temporal resolution in the low-intensity regime has been observed by other workers and was attributed to late-time emission (straggling) of slow electrons from CsI (Stradling *et al.* 1980).

An additional result obtained from these measurements is shown in figure 3. A slight misalignment of the mode-locked oscillator cavity occasionally produced modulated or even multiple pulses. The 4ω fiducial in the lower part of figure 3 shows such a situation where the main pulse is followed by a weaker post-pulse after about 170 psec. As can be seen in the upper part of the figure this post-pulse, although much weaker, gives rise to a strongly enhanced emission in the soft x-ray spectral region. This is most likely due to the higher absorption efficiency experienced by the second peak as a result of the increasing scale length of the expanding plasma. The enormous impact of a temporal modulation of the laser pulse on the history of the x-ray emission suggests that great care has to be taken when relating the 'peak' of an observed x-ray signal to the 'peak' of the irradiating pulse. Therefore in discussing x-ray emission from laser-produced plasmas precise information on the temporal profile of the driving laser pulse becomes indispensable.

In conclusion, we have demonstrated the feasibility of synchronously recording the soft x-ray emission and a UV timing fiducial with a hybrid photocathode. We used this experimental arrangement to demonstrate that the thermal x-radiation from an Al plasma peaks 20 ± 15 psec after the peak of the incident 100 ps laser pulse.

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