Time-Resolved X-Ray Spectroscopy of Laser Heated Plasmas

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Abstract. Recent experimental results are presented on time-resolved spectroscopy of laser produced plasmas. In particular, K-shell emission of H-like and He-like Aluminium plasmas was investigated. The electron temperature was measured taking into account the opacity of the plasma. Re-heating effect due to the interaction of a delayed laser pulse with the preformed plsma was observed and studied. The results have been compared with the prediction of a steady state atomic physics numerical code.

X-RAY EMISSION AND TEMPERATURE MEASUREMENTS

The interaction physics of intense laser radiation with coronal plasmas of interest for inertial confinement fusion is being currently studied in many laboratories worldwide. Relevant results were obtained in a recent experiment supported by the EC Programme for the Access to the Large Facilities and performed at the Rutherford Appleton Laboratory. Test plasmas were produced by laser irradiation and consequent explosion of thin foil Al targets. The preformed plasma was then interacted after a suitable delay with a focused 600 ps laser pulse at an irradiance of 10^{15} W/cm^2. The test plasma was fully characterised[1,2] in terms of its electron density distribution and temperature evolution. The temperature measurements were performed by means of time resolved X-ray spectroscopy, using an X-ray streak camera coupled with a TlAP crystal spectrometer, shown in

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Fig1. K-shell emission lines of He-like and H-like Al plasma were investigated. Line intensity profiles were found to be well fitted with a Gussian profile. The Ly-γ (1s-4p) to the He-γ ($1s^2$-1s4p) intensity ratio was measured at different times before and after the high irradiance delayed interaction.

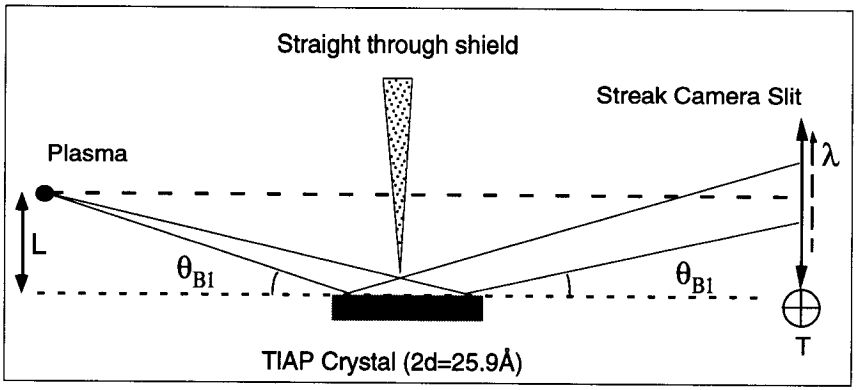

FIGURE 1. Crystal set up for time resolved X-ray spectroscopy.

The electon temperature was then obtained taking into account the opacity of the plasma. A significant re-heating of the preformed plasma was observed during the delayed interaction. The results have been compared with the prediction of the steady state atomic physics numerical code RATION[3].

Time-Resolved X-Ray Spectra

A typical time-resolved spectrum is shown in Fig.2a, while Fig.2b shows a 1-D spectral lineout taken 500 ps after the peak of the Heβ line emission and integrated over 50 ps, which is also the temporal resolution of the spectrum. Emission lines from the Heβ to the Lyδ are clearly visible with the Lyγ and Lyδ emerging from the He-like continuum. Line intensity profiles were found to be well fitted by a Gaussian profile with $\Delta\lambda_{FWHM} = 40\text{m}\text{Å} \pm 10\%$. All the lines, except the Heε and Lyβ, are well resolved allowing a direct evaluation of the line intensity. With the available spectral resolution (set by the source size), the Lyβ line is only partially resolved being merged with the Heε and higher quantum number He-like lines and with the He-like continuum edge.

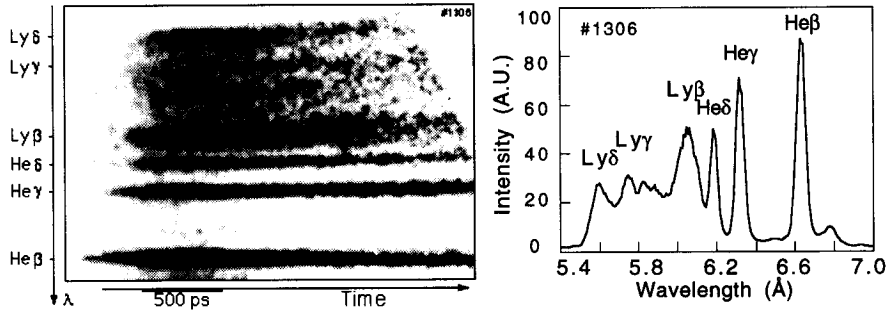

FIGURE 2. a) Time-resolved spectrum of K- shell Al plasma emission. Irradiance on target: 3.2 10^{13} W/cm^2. b) Lineout taken 500 ps after the peak of emission.

A systematic study of such kind of spectra are presently in progress both for basic studies of atomic and plasma physics[4] and for optimisation of X-ray sources for applications[5].

Temporal Evolution of Electron Temperature

The evolution of the electron temperature is obtained from time-resolved X-ray spectra by measuring, at the different times, the intensity ratios of suitable pairs of lines, provided that additional information on the physical plasma condition is available. In fact, simple analytical or semi-analytical models of plasma equilibrium (local thermodynamic or coronal equilibrium) cannot be applied over the whole plasma, due to the wide range of temperatures and densities typical of such inhomogeneous plasmas. Therefore, numerical models are necessary in order to perform detailed balance of all available ionic levels in a mixed collisional-radiative equilibrium. The steady state RATION code was used in our case since, in our conditions, atomic physics processes are typically faster than plasma hydrodynamic processes. Electron density was measured independently by optical interferometry on the plasma[1,2].

Finally, plasma opacity effect on the emission lines were also taken into account for temperature measurements. Calculations showed that, typically 1.5 ns after the peak of the plasma heating pulse, plasma opacity effects can be neglected in our case. Consequently, accurate temperature measurement could be obtained at the time of the delayed intaraction, that is, 2.5 ns after the peak of the plasma heating pulse.

In Fig. 3a a time resolved spectrum is shown, as obtained from the plasma emission in the two subsequent stages of i) plasma formation and heating ii) delayed interaction and re-heating. In Fig 3b the evolution of the electron plasma temperature is plotted, as obtained from mesurements of the Ly-γ to He-γ line ratio at different times.

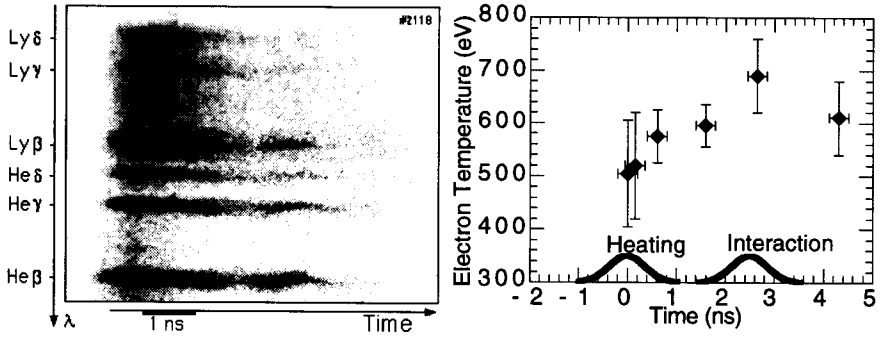

FIGURE 3. a) Time-resolved spectrum of K- shell Al plasma emission including the delayed interaction re-heating. Irradiance at plasma formation: 2.8 10^{13} W/cm^2. Irradiance at delayed interaction: 3.0 10^{14} W/cm^2. Peak plasma density during delayed interaction: 10^{20} cm^{-3}. b) History of electron temperature.

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