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X-RAY EMISSION AS A DIAGNOSTIC OF LASER PRODUCED PLASMAS ON THIN FOIL PLASTIC TARGETS

D.Batani*, V. Biancalana, F. Bianconi, A. Giulietti, D.Giulietti, L.A. Gizzi**

Istituto di Fisica Atomica e Molecolare, via del Giardino,7 Pisa
*Dipartimento di Fisica, Universita' di Milano
**Blackett Laboratory, Imperial College - London, U.K.

ABSTRACT

Non thermal tails in electron velocity distribution have been observed at nominal laser intensities above 6 10^{12} W/cm^2 in plasmas generated by irradiation of thin foil targets. A model accounts for the electron acceleration as due to plasma waves excitated by "two plasmon decay" process. This assumption is also confirmed by spectroscopic measurements in the visible region.

Laser irradiation of thin foils has been developed recently as a technique of laser-plasma interaction studies [1-3]. Plasmas produced in this way are useful both to simulate the corona of inertial confinement fusion pellets and to achieve conditions of interest for X-ray lasers[4]. To study plasmas as incoherent X-ray sources, thick targets are generally preferred, because of the higher conversion efficiency obtainable. We did an experiment on X-ray emission from thin foil plasmas in order to better understand the evolution of the laser-plasma interaction we already studied with time-resolved optical spectroscopy.

From the spectrum of the X-UV continuum the electron temperature can be calculated; moreover a careful analysis of the spectral features can supply us with important information on the electron energy distribution function, and eventually evidence deviations from the Maxwellian generally assumed at the thermal equilibrium[5,6]. For a fully ionized plasma as we obtain by irradiating plastic foils, the continuum is mostly generated by electron-ion collisions leading to the bremsstrahlung emission, whose spectral intensity is

$$I(\lambda) \approx 2\ 10^{-27} [(Z^* n^2 \varepsilon^{1/2}) / (T^{1/2} \lambda^2)] \exp[-(hc/K_B T\lambda)] g \text{ erg sec}^{-1} \text{ cm}^{-4},$$

where $Z^* = \langle Z^2 \rangle / \langle Z \rangle$, the averages being calculated over all the ionization states; n and T are the electron density and temperature respectively; ε is the dielectric constant; $g \approx 1$ is the Gaunt factor. $I(\lambda)$ has its maximum value at $\lambda \approx 6.2\ 10^3 / \theta$ Å , θ being the electron temperature expressed in eV. This maximum lies in the X-UV portion of the spectrum for plasma temperature in the range of .1 to 1 keV, as usually obtained in laser plasmas.

It is possible to infer roughly the curve $I(\lambda)$ from a set of intensity measurements obtained with X-ray filters of different absorptivity put in front of a detector. In fact the ratios between intensities reaching the detector when two foils of the same material but different thikness D_1 and D_2 are subsequently used, in the assumption of Maxwellian distribution, is

$$I_1/I_2 = \{\int \lambda^{-2} \exp[-(hc/K_B T\lambda) - \kappa(\lambda) D_1] d\lambda\} / \{\int \lambda^{-2} \exp[-(hc/K_B T\lambda) - \kappa(\lambda) D_2] d\lambda\}$$

where $\kappa(\lambda)$ is the absorption coefficient of the filter material, which is assumed to be known as well as the spectral sensitivity of the detector. In this way a set of measurements of the quantities I_i/I_j can allow to evaluate T in the assumed Maxwellian distribution.

Eventhough this method is not very accurate, it is interesting because it allowed to evidence in several experiments the presence of a secondary electron population of temperature T_h higher than the Maxwellian T. This secondary population is generally explainable in terms of electron acceleration by electron plasma waves[7,8,9]. Plasma waves can grow in presence of anelastic scattering of the laser light[10]. Close to the critical density n_c, resonance absorption and eventually "parametric decay" of the laser light can produce large amplitude electron waves; at $n < n_c/4$ electron waves can be generated by stimulated Raman and two plasmon decay processes.

These waves are able, with their strong longitudinal electric field, to accelerate electrons whose velocity component in the direction of the wave propagation is near to the phase velocity of the wave itself, $v_\phi = v_T [3 + (k\lambda_D)^{-2}]^{1/2}$, where v_T is the electron thermal velocity, k is the wavevector of the plasma wave and λ_D is the Debye length. Notice that electrons can experience, for a time of about the inverse of the electron-ion collision frequency, an electric field whose numerical value is up to $E \approx n^{1/2}$ V/cm, where the plasma density n is expressed in cm^{-3}.

The maximum energy gain for trapped electrons is:

$$\Delta E_{max} = 2m\, v_\phi^2 (v_E/v_\phi)^{1/2} [1 + (v_E/v_\phi)^{1/2}] \quad ,$$

$v_E = eE/m\omega$ being the quiver velocity of the electron in the field of a plasma wave of pulsation ω. The higher the phase velocity of the plasma wave, the larger the energy gain, but the smaller the number of electrons available in the distribution. The fraction of electron population that can be accelerated by a wave of phase velocity v_ϕ is limited in the range:

$$v_\phi - (2 v_E v_\phi)^{1/2} \leq v \leq v_\phi \quad ,$$

whose width depends on the wave field amplitude. This latter can be estimated from the field amplitude parameter: $v_E / v_\phi = n^*/n_c$, where n^* is the peak density variation associated to the wave.

In our experiment the beam from a Nd laser ($\lambda = 1.064$ μm, $E_L \leq 3$ J, $t_L = 3$ nsec), was normally focused on a thin plastic foil target by an f/8 lens. The focal spot diameter was ≈ 60 μm FWHM and the maximum intensity was $I_L \approx 2\ 10^{13}$ W/cm^2. The prepulse energy level was kept below 10^{-4} the main pulse and it was experimentally checked that this level could not produce any early plasma formation. X-ray signal was detected by a silicon P-I-N detector (025-PIN-125 produced by Quantrad Corporation) filtered with Aluminium filters of thickness between 1.6 and 13 μm. This detector was placed 20 cm away from the plasma.

In the same experiment the light emitted at 90° to the laser beam was spectrally and time resolved using a spectrometer coupled with a visible streak-camera. Emission of 2ω and $3\omega/2$ was analyzed and used as a temperature diagnostics. Typical temperatures obtained were $T \approx 500$ eV for film of thickness $d \approx 1.5$ μm irradiated at intensity $I_L \approx 10^{13}$ W/cm^2.

We also got images of our X-ray source with the help of a pin-hole camera, so that the plasma could be seen at 90° or "in front" but with a 45° azimuthal angle. Images were recorded by a 20 μm pin-hole filtered with a 1.6 μm Al filter on kodak DEF and SB X-ray films. The pin-hole camera magnification was $M \approx 5$. A complete report on results obtained in this experiment has been published elsewhere[11].

We only discuss here some aspects of the temperature measurements performed with the method of multiple filters mentioned above. Fig.1 shows the plot of the nominal temperature obtained from the intensity ratio with four different filter pairs. We see that the nominal temperature does not depend on the filter pair only for $I_L \leq 6\ 10^{12}$ W/cm^2. For larger laser intensities there is an "anomaly": T is bigger the closer to 1 is the ratio between the thickness of the "thin" filter and that of the "thick" filter. This result is easily interpretable in terms of the creation of supra-thermal tails of hot electrons in the velocity distribution, and hence of the presence of a "hard" component in the X-ray spectrum (with $h\nu >> \theta$), stronger than for a normal bremsstrahlung spectrum. It is important to notice that 6 10^{12} W/cm^2 was also found to be the threshold laser intensity for the generation of the harmonic 3/2, which is strictly related to the two plasmon decay[12].

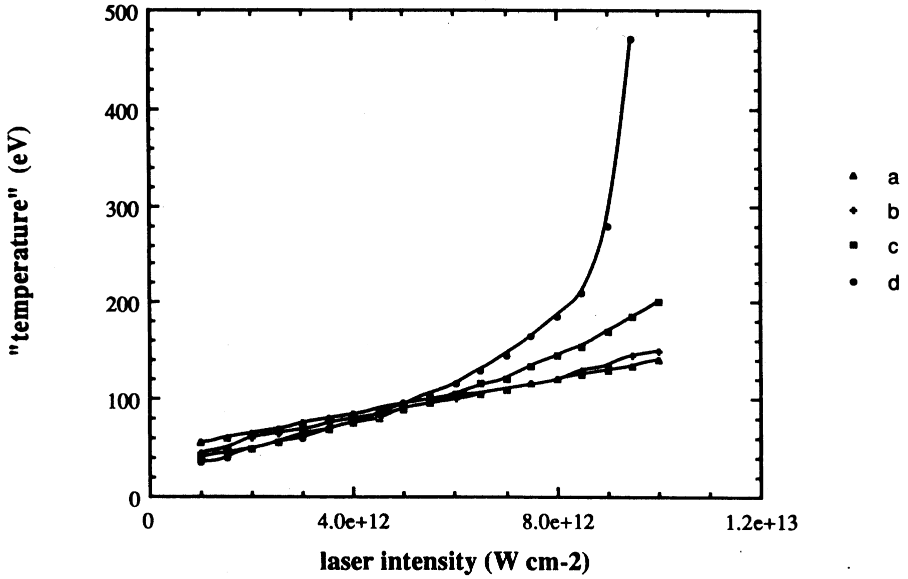

Fig.1 Nominal temperature v/s laser intensity obtained with different Al filter pairs. Target foil thickness: 1.5 μm. Curve (a) refers to the (13 μm; 1.6 μm) filter pair, curve (b) to (13μm; 2.4μm), curve (c) to (13μm; 4μm) and curve (d) to (13μm; 6μm).

The maximum contribution to the deviation of the electron density distribution from the Maxwellian is due to the plasma waves at lowest phase velocity, $v_{\phi\,min} \approx 3.6\ v_T$ which is determined by the Landau damping limit. Assuming $n^*/n \approx 0.1$, we find $(2\ v_E v_\phi)^{1/2} \approx 1.5\ v_T$. As a consequence we estimate in our case $v_E/v_\phi \approx 10^{-2}$ and $\Delta E_{max} \approx 1.5$ keV.

We consider now two electron populations at different temperatures, a main component matching roughly the (a) plot of Fig.1 and a higher temperarure component at 1.5 keV. After numerical elaboration[12], we obtain a new plot for the temperature of the main component, as shown in Fig.2.

Notice that the temperature of the X-ray source is definitely lower than 500 eV we measured from harmonic spectra. This is because most of the X-ray emission occurs early in the pulse, when the plasma is overdense and relatively colder. On the contrary, according to our

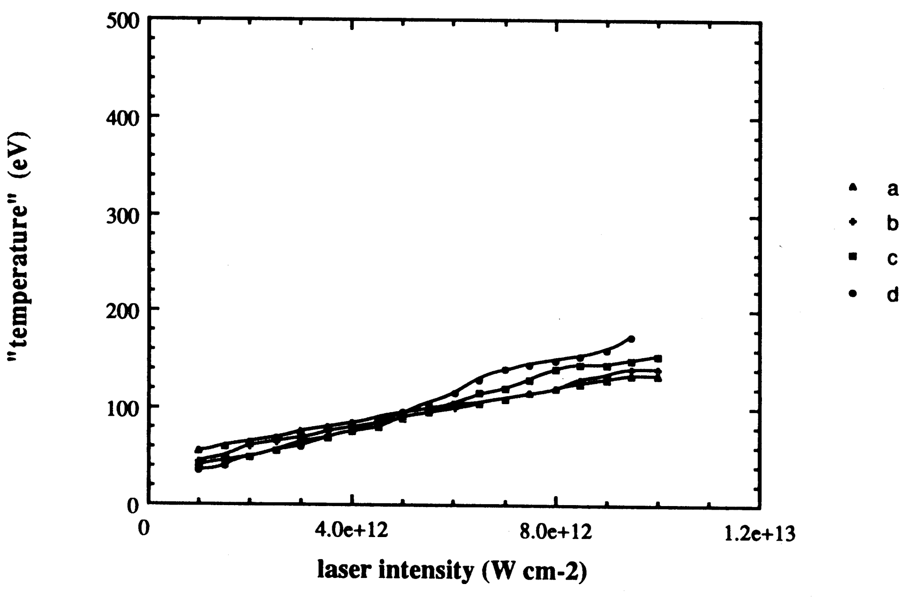

Fig.2 Thermalized electron temperature v/s laser intensity obtained from data of Fig.1 after the elaboration taking in account the supra-thermal population.

hypotesis of two-plasmon-decay accelerating waves, the suprathermal component is generated later at the peak of the pulse, when the laser pumping of the plasma waves reaches its maximum efficiency.

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