DIRECT COMPARISON OF ELECTRON DENSITY MEASUREMENTS IN LASER-CREATED PLASMAS USING STARK BROADENING AND SATELLITE LINE INTENSITIES

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Spectral line profiles, broadened mostly by Stark effects from electric fields produced by charge particles, and diélectronic satellite line intensities have recently been used for determining electron densities in the dense region of laser-created plasmas [1-3]. We present here a direct comparison of electron density measurements in the conduction region of laser created plasmas on a plane target using these two techniques.

Experiments were carried at the GRECO laser facility, using the Nd phosphate glass laser at its second harmonic (0.53 μm) and 600 ps pulse length. The laser was focused on a 160 μm focal spot in which was centered a 25 or 50 μm diameter aluminum dot implanted on a carbon substrate. Laser intensities were in the range 1×10^{14}-3×10^{14} W/cm^2. The $1s4p$-$1s^2$ He-like transition, the 4p-1s H-like transition and the Ly α satellites were recorded on the same spectrum with a PET flat crystal spectrograph. Spot spectroscopy provided quasi-homogeneity and low reabsorption along the line of sight which was tilted 7° out the target surface. 3 μm resolution along the laser axis was obtained with an imaging knife-edge placed 1 mm apart from the target [4].

Electron densities were deduced comparing the He-like and H-like resonance Stark broadened lines to theoretical profiles calculated for H-like lines [5]. Lines of $n = 4$ quantum number are the most suited for the measurement as they merge out the continuum and are not much reabsorbed. Instrumental and Doppler broadening were taken into account. The electron density and an optical depth around 1.5 were introduced as parameters to obtain the best fit of the experimental data. Figure 1 shows the precision of the measurement on a He-like profile. The assymetry of the profile due to blended forbidden lines decreases slightly the accuracy of the density measurement.

Satellite line intensities were calculated in a collisional radiative model including photon pumping effects [6-7]. The complete experimental satellite spectra were compared to the theoretical ones. A Voigt profile broadened by an instrumental profile of 4 mA width reproduces better the line shapes. The gaussian width includes 2 mA Doppler broadening. The Lorentzian width is introduced as a parameter and appears to be compatible with recent Stark broadening theory [8] (2 mÅ at $n_e = 10^{22}$ cm^{-3}). Figure 2 shows an experimental spectra measured with 10 μm spatial resolution for 22 J of laser energy

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incident on a 50 μm diameter and the fit of the theory obtained for a density of 1.0 x 10^{22} cm^{-3}.

Typical electron density measurements obtained for several shots conditions (different laser energy and aluminum dot diameter) are shown on figure 3. Stark broadening of the n = 4 resonance lines provides the whole electron density profile while the satellite lines give a single value of the electron density at the satellite peak intensity. The error bar on these preliminary result is rather large. One of the reasons for it is that the measured density is close to the region where opacity effects become important. Indeed, taking into account radiative transfer across the plasma length cuts down the region of fast dependence of the line intensity ratio versus electron density as can be seen on figure 4.

Figure 3 shows that the satellite lines diagnostic gives electron densities compatible but systematically higher by about 50 % than the Stark widths diagnostic. This discrepancy can be due to integration effects since satellite lines are emitted at a position close to H-like and He-like resonance lines [7] but are emitted only briefly near the maximum of the laser pulse [9].

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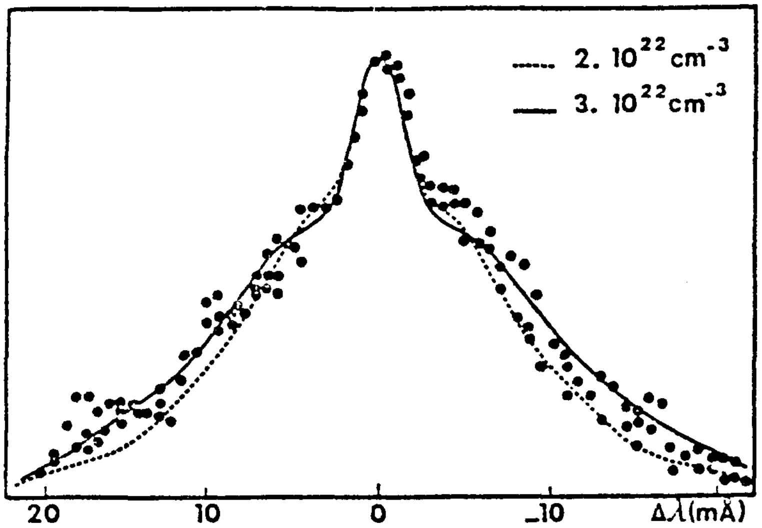

Figure 1 : Profile of the 1s4p-1s^2 Al^{11+} line. Theoretical profiles are the full and dotted lines (ion dynamics is included). Experimental points are obtained for an incident intensity of 3.10^{14} W/cm^2.

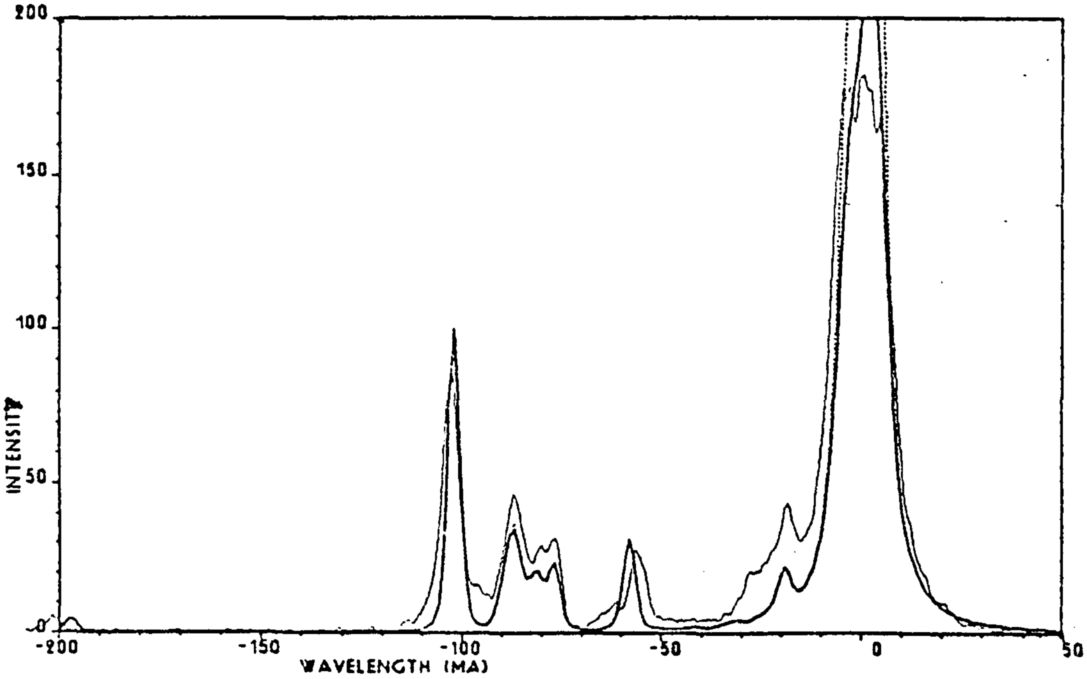

Figure 2 : Dielectronic satellites of the Lyα line. The experimental spectrum (noisy curve) is fitted with theoretical ones obtained for the following conditions : $n_e = 10^{22}$cm^{-3}, T_e = 400 eV, optical thickness of the plasma = 25 µm, the ratio of the populations of hydrogenic and helium-like ions is half of the collisional-radiative equilibrium value.

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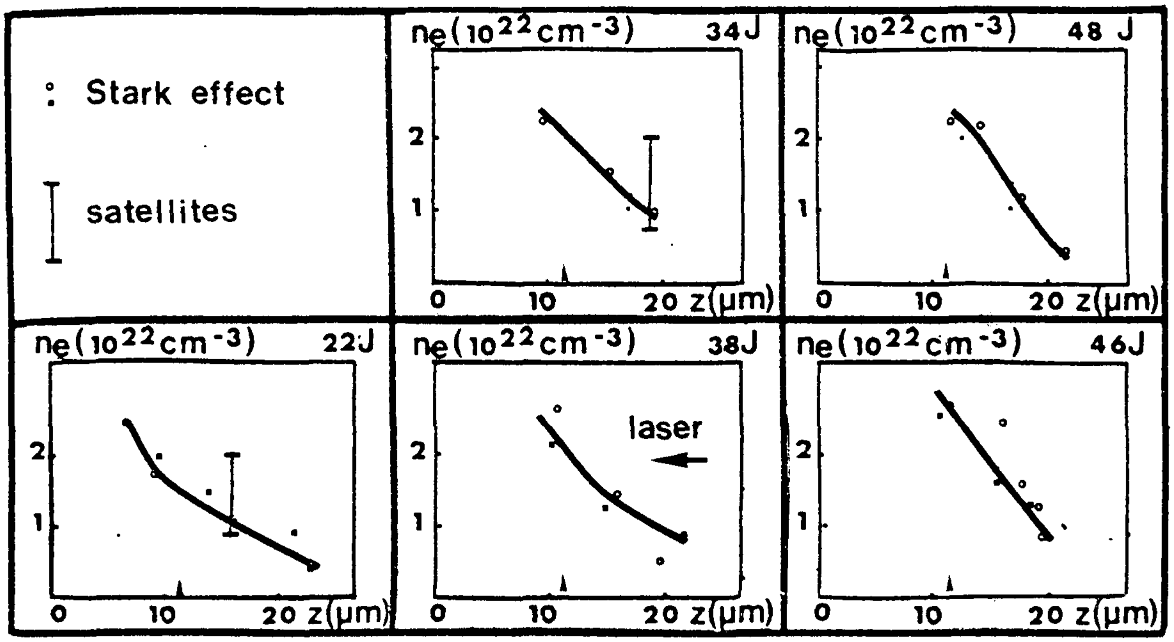

Figure 3 : Electronic density along the laser axis for several laser shots (22 to 48 Joules). The upper profiles obtained on a 50 μm diameter aluminum microdot and the lower on a 25 μm diameter microdot give similar results. The arrow indicates the maximum of emission of the Al^{11+} $1s4p-1s^2$ line. Circles are measured on this Al^{11+} line, and square from the Al^{12+} 4p-1s line.

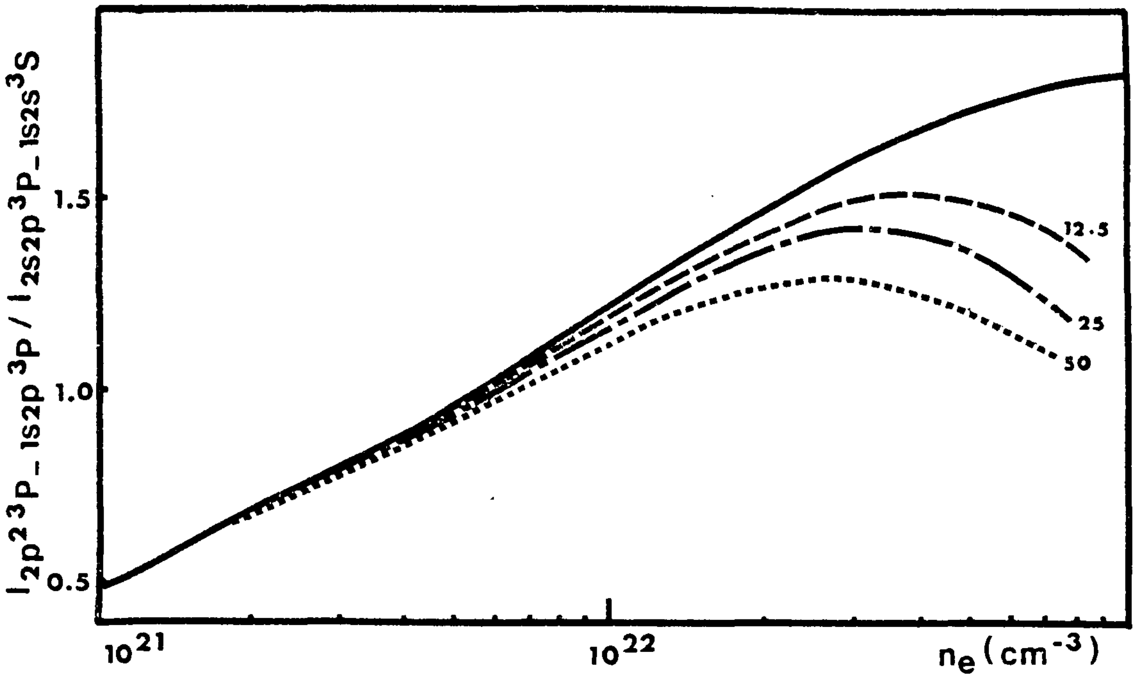

Figure 4 : Effects of reabsorption on the intensity ratio of Ly α satellite lines. Ratio of the $2p^2\,^3P-1s2p\,^3P$ to $2s2p\,^3P-1s2p\,^3S$ line is plotted versus electronic density. Electronic temperature has been fixed at 400 eV. Full line : no reabsorption – Dotted lines : 12.5 μm, 25 μm and 50 μm optical thickness of the plasma.

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