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X-ray conversion on gold spheres. OMEGA experiments.

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As LMJ and NIF ICF hohlraum walls will be made of high-Z materials, X-ray conversion efficiency measurement experiments with gold spheres are relevant to ICF studies since direct uniform irradiation on spheres produces one dimension plasmas without magnetic fields.

The goals of these series of experiments were to discriminate atomic physics models for 2D hydro-rad simulations with measurements of soft x-ray conversion efficiencies (CEs) and estimations of M-band proportion on gold coated spheres at 3 laser fluxes and plasma characterisation via electron temperature assessments with spectroscopy technique (intensity ratio of iso-electronic lines) or a Thomson scattering diagnostic. This work was a CEA/NNSA collaboration for conversion efficiency studies.

OMEGA laser is a 60-beams facility delivering a maximum of 30 kJ at 3ω (λ=351 nm) which is designed for direct drive implosions. These experiments have been held with 59 beams of direct drive (1 beam used for Thomson scattering [1] measurements at 4ω) on 1mm in diameter gold spheres giving 9.7×10^{14} W/cm^2, 3.5×10^{14} W/cm^2 and 1.3×10^{14} W/cm^2 laser intensities on target with SG1018 square pulse shapes (1ns, ~470 J per beam), SG2005 (2ns, ~340 J) and SG3015 (3ns, ~180 J) respectively. The 59 drive beams were equipped with DDP (Dynamic Phase Plates) SG4 and DPR (Double Polarisation Rotator).

The targets were coated spheres of plastic 950 µm in diameter. The coating was pure gold (5µm) or gold with Ti / V layers inside the gold coating (first inner layer of gold (5µm thick), 2nd layer of titanium (0.1µm), 3rd layer of vanadium (0.1µm) and a last layer of gold (0.1µm).

CEs obtained by the broadband spectrometer DMX are shown to discuss x-ray conversion and time and spectrally resolved imaging are presented as well as the iso-electronic line spectroscopic technique used to assess the plasma electron temperature versus time for low and intermediate fluxes.

DMX is a channels broadband spectrometer (from 0-20 keV), time resolved x-ray diodes array [2] measuring the x-ray power emitted by the target. It was configured with 17 channels at the time of the experiments to look after the soft x-ray emission and the gold M-band from from 2 to 4 keV. The spectral range of each channel was adjusted by choosing appropriate filter materials.

Figure 1 shows conversion efficiencies obtained from gold coated spheres for laser intensities going from 10^{14} W/cm^2 to 10^{15} W/cm^2. The overall relative uncertainty is 20% on x-ray power from DMX data considering the filter transmission and detector sensitivity calibrations and the data reduction treatment necessary to take into account the broadband response of the DMX channels. CEs decrease with higher laser intensities going from ~80% ± 10% at low flux, ~67% ± 7% at intermediate laser flux and ~55% ± 5% at high laser flux.

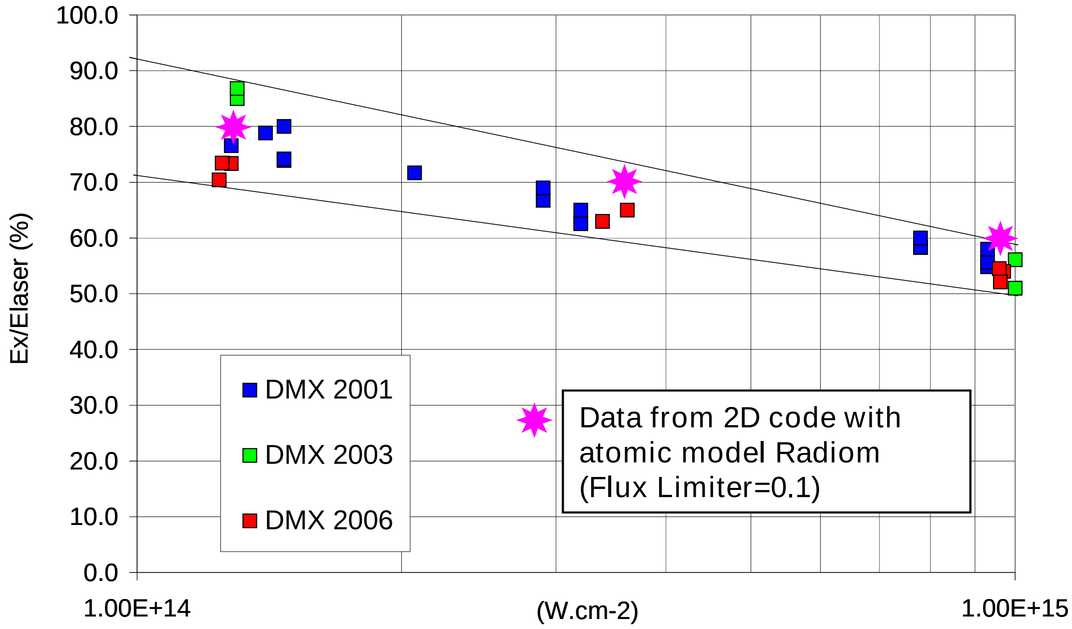


Figure 1 Gold x-ray conversion efficiencies versus laser intensity.

The spectroscopic technique employed gives electron temperature via the intensity ratio of iso-electronic lines from 2 ions which have close atomic numbers (Z=22 for Ti and Z=23 for V). The considered iso-electronic lines 1s3p-1s^2 (He$_\alpha$) lines are the one at 4750eV of Ti^{20+} ions and the He$_\alpha$ line at 5200eV of V^{21+}. The assumptions taken to assess electron temperature are the followings: simple plasma with Ti and V ions at same temperature T and at such low density that one can consider only 2 bodies processes of the type $X^{n-} \leftrightarrow X^{(n+1)-} + e-$. This let us say that all photons come from a single deexcitation of one ion and the number of these photons is proportional to the number of ions responsible for photon emissions.

The partition function of the system is $Z = \sum_i g(E_i) e^{-E_i/kT}$ where energies E_i correspond to different ionization degrees. The iso-electronic line ratio technique is interesting because the $g(E_i)$ coefficients are the same for Ti et V. at equilibrium, relative line intensities of Ti et V only depend on relative ion densities.

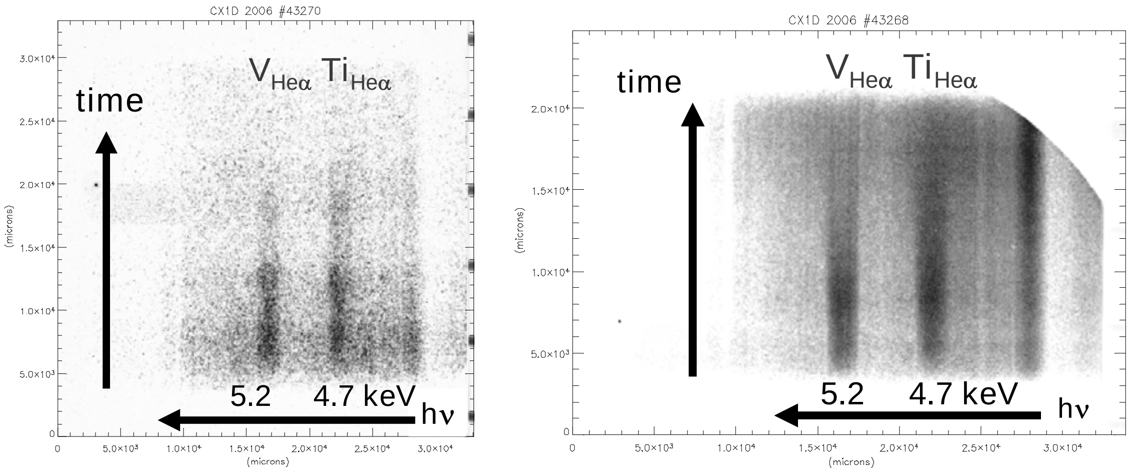
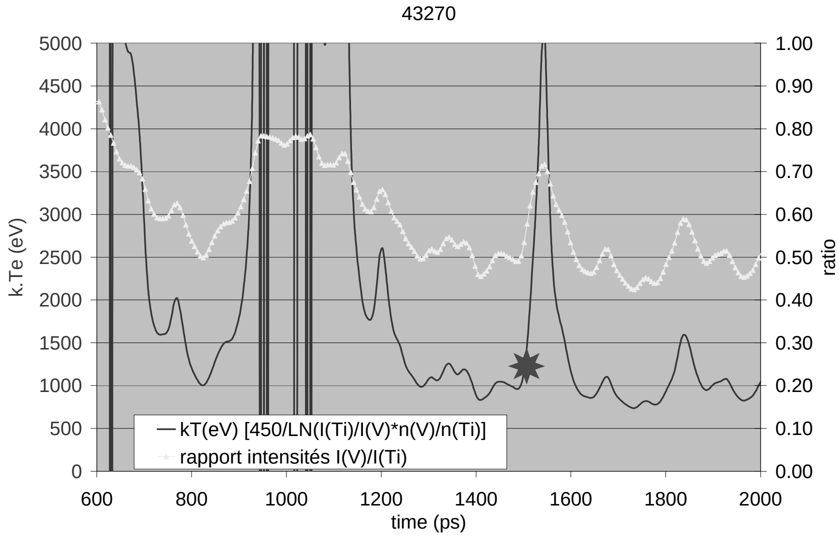


Figure 2 X-ray spectra showing time history of titanium and vanadium He_α intensities for laser intensities of 10^{14} W/cm^2 (left) and $3\text{x}10^{14}$ W/cm^2.

In our case considering He_α line @4750 eV and He_α line @ 5200 eV, one have: $\frac{I_{\mathrm{Ti}}}{I_{\mathrm{V}}} = \frac{n_{\mathrm{Ti}^{20+}}}{n_{\mathrm{V}^{21+}}} = \frac{n^0_{\mathrm{Ti}}}{n^0_{\mathrm{V}}} e^{-(E_{\mathrm{Ti}}-E_{\mathrm{V}})/kT} = \frac{n^0_{\mathrm{Ti}}}{n^0_{\mathrm{V}}} e^{450\mathrm{eV}/kT}$ and then $kT = \dfrac{450\,\mathrm{eV}}{\ln\left(\dfrac{I_{\mathrm{Ti}}}{I_{\mathrm{V}}} \dfrac{n^0_{\mathrm{V}}}{n^0_{\mathrm{Ti}}}\right)}$.

Line intensities were obtained by taking into account: film conversion density versus exposure, subtraction of gold background, correction of filter transmissions and gold photocathode sensitivities at 4.7keV and 5.2keV. At low flux, experimental electron temperatures are close to those given by 2D code simulation with the atomic physics model Radiom and a value of the flux limiter of 0.1. At intermediate flux ($3\text{x}10^{14}$ W/cm^2), experimental data show a fast drop in Te, inconsistent with simulation. In our case, iso-electronic technique hard to believe because it gives a Te of 1keV at 1.5ns for both fluxes.



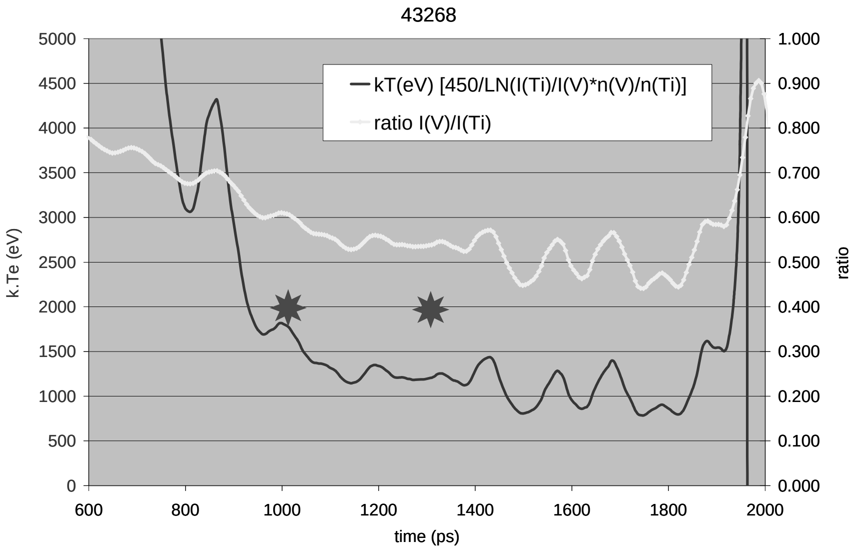


Figure 3 Titanium and Vanadium He$_\alpha$ line intensities and the ratio I(V)/I(Ti) versus time for laser intensities of 10^{14} W/cm^2 (up) and 3x10^{14} W/cm^2. Stars correspond to electron temperature given by 2D simulations.

In summary, a coherent set of conversion efficiencies over 3 years covering the range 10^{14} W/cm^2 up to 10^{15} W/cm^2 will let us validate simulation codes. The CEs for gold are 80 % at 10^{14} W/cm^2 with 12% of M-band (x>2keV), 67 % at 3x10^{14} W/cm^2 with 12% of M-band and 55 % at 10^{15} W/cm^2 with 2% of M-band. Data reduction from the iso-electronic technique is difficult in our case.

References

[1] E.L. Dewald et al., 48th APS DPP Philadelphia PA, November 2006

[2] J-L. Bourgade et al., Rev. Sci. Instrum. 72, 1173, (2001).