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Underdense radiation sources: Moving towards longer wavelengths

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Abstract. Underdense radiation sources have been developed to provide efficient laboratory multi-keV radiation sources for radiography and radiation hardening studies. In these plasmas laser absorption by inverse bremsstrahlung leads to high x-ray conversion efficiency because of efficient ionization of the low density aerogel or gas targets. Now we performing experiments in the soft x-ray energy regime where the atomic physics models are much more complicated. In recent experiments at the NIKE laser, we have irradiated a Ti-doped SiO_2 aerogel with up to 1650 J of 248 nm wavelength light. The absolute Ti L-shell emission in the 200-800 eV range is measured with a diagnostic that uses a transmission grating coupled to Si photodiodes. We will give an overview of the temporally-resolved absolutely calibrated spectra obtained over a range of conditions. Eventually we hope to extend our studies to x-ray production in the EUV range.

1. INTRODUCTION

Accurate understanding of x-ray production mechanisms is essential for design and fabrication of x-ray sources that are used for backlighting, material testing and EUV lithography. Although the x-ray production is important, the physical processes that contribute to this essentially non-LTE regime are difficult to study because plasma gradients profoundly affect the physical observables. The outstanding discrepancy between data and calculations of laser-produced plasmas in recombination has been in evidence since the 1980's [1]. Predictions of the x-ray source duration, importantly for times greater than the laser pulse duration are inaccurate. While the problem might be in the hydrodynamics, there are also indications that non-LTE atomic kinetics may be the dominant cause of discrepancies. Recent international workshops on non-LTE kinetics have uncovered vast discrepancies in predictions from 16 different codes for plasma temperature and density cases that were chosen for relevance to laboratory plasma studies [2]. The inability to accurately model x-ray laser recombination schemes is a prominent illustration that the models are incomplete.

At the temperatures and densities of typical laser-produced plasmas, the emission of L-shell, M-shell and even N-shell can affect the energy balance much more significantly that K-shell emission. In addition, as the Z of the element increases, the complexity of the calculated atomic model also increases. For instance, a relatively complete model of a Ti Li-ion can have up to 20,000 levels. An approximate model of the same ion stage may need to be reduced to approximately 100 levels in order to run simulations with the current computational capabilities. Figure 1 shows a comparison of the Ti L-shell lines calculated by a detailed atomic physics code, HULLAC, compared to those calculated using FLY. Although simpler models may allow for reasonably accurate calculation of energy balance, this figure

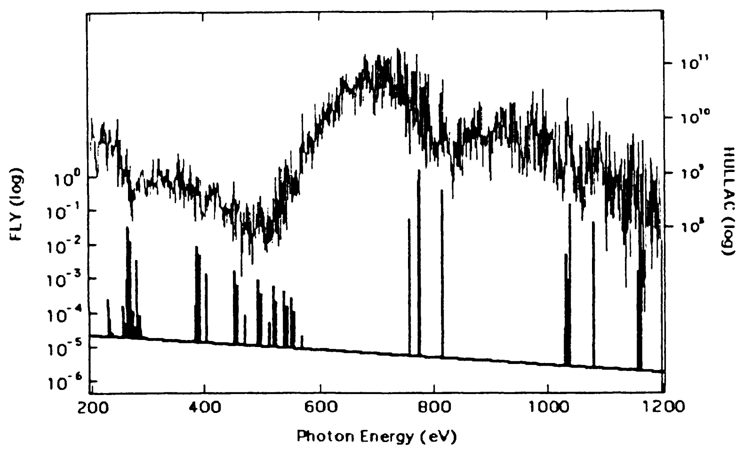

Figure 1. Calculations of Ti L-shell spectra by HULLAC (top) and FLY (bottom) for $T_e = 400\,eV$ and $n_e = 10^{21}\ cm^{-3}$.

shows that the richness of the spectra is lost in the simpler model. Clearly, there is a need for data to validate the reduced models.

2. NON-LOCAL THERMODYNAMIC EQUILIBRIUM EXPERIMENTS

The experiments were performed using the NIKE laser to create plasmas from cylindrical aerogel targets. The laser was configured to deliver up to 37 beams of 0.248 µm wavelength light incident within a cone angle of 12° from the axis of the cylinder. The intensity of the overlapped beams of the laser was varied from 1×10^{12} to $5 \times 10^{13}\ W/cm^2$ by using different combinations of the spot size and number of beams on target. The average energy of a single beam for all shots was ~42.5 J. The risetime of the laser pulse is ~250 ps.

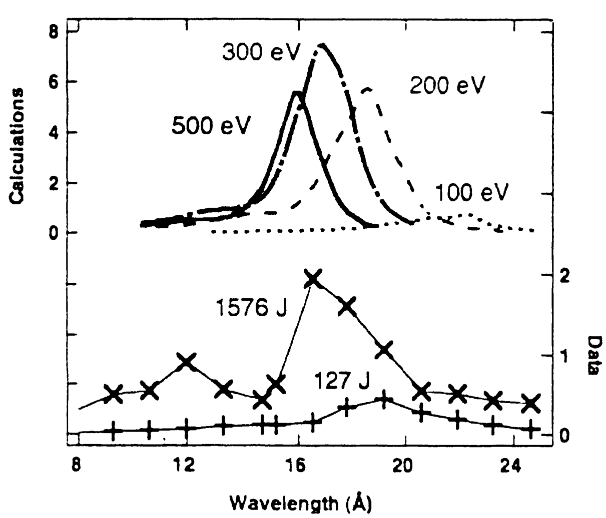

Figure 2. Calculations and data for a Ti-doped aerogel heated by the NIKE laser. The calculations are for a 1 mm long plasma having an ion density of $6 \times 10^{19}\ cm^{-3}$ and are identified by their electron temperature. The values of intensity on the vertical axes are $\times 10^{17}$ in units of ergs/cm^{-3}/sec/sr/Å.

The use of low density aerogel foams ~3 mg/cc doped with 3-6 at.% Ti permit us to measure the temporal evolution of the K and L-shell emission of highly-ionized species. Under these laser conditions, the foams are volumetrically heated [3, 4] [5] [6]. The primary diagnostic was a transmission grating spectrometers (TGS) that provided absolutely calibrated, time-resolved Ti L-shell emission measurements [7]. Figure 2 shows the temporally resolved data as a function of wavelength at 4 ns. Here we have reduced the data by subtracting out the Si and O contribution to the spectrum as measured from a non-doped SiO_2 target of the same density and under the same laser irradiation conditions. The data compared to calculations shows that the peak value shifts to lower temperature for the lower energy shot.

3. CONCLUSIONS

These experiments provide valuable L-shell spectra that can be analyzed to determine the ionization balance, the absolute emissivity and the temporal dependence of the plasma. In the future, higher spectral resolution will enable the creation of benchmarks that will be used to refine and validate the non-local thermodynamic equilibrium models.

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