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# Measurement of XUV-absorption spectra of ZnS radiatively heated foils

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**Abstract**

Time-resolved absorption of zinc sulfide (ZnS) and aluminum in the XUV-range has been measured. Thin foils in conditions close to local thermodynamic equilibrium were heated by radiation from laser-irradiated gold spherical cavities. Analysis of the aluminum foil radiative hydrodynamic expansion, based on the detailed atomic calculations of its absorption spectra, showed that the cavity emitted flux that heated the absorption foils corresponds to a radiation temperature in the range 55–60 eV. Comparison of the ZnS absorption spectra with calculations based on a superconfiguration approach identified the presence of species $Zn^{6+}$–$Zn^{8+}$ and $S^{5+}$–$S^{6+}$. Based on the validation of the radiative source simulations, experimental spectra were then compared to calculations performed by post-processing the radiative hydrodynamic simulations of ZnS. Satisfying agreement is found when temperature gradients are accounted for.


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## 1. Introduction

The energy exchange in stellar interiors is dominated by radiative transfer, which is determined by the absorption of medium-Z elements, even though they represent only a small fraction of the stellar mass [1,2]. This stems from the strong absorption structures of medium-Z elements in the X-ray and XUV range that match the Planckian spectrum of the radiated flux. Further, the study of absorption coefficients is of great interest for the indirect scheme of inertial confinement fusion, where the deposited energy is dominated by the radiative properties of the atomic species used in hohlraums and pellets layers [3].

In the present experiment the absorption coefficients of zinc sulfide (ZnS) and aluminum plasmas in local thermodynamic equilibrium (LTE) conditions were characterized by measurements of their absorption spectra. ZnS and Al foils were heated by the radiation emitted by a gold spherical cavity. The ZnS absorption spectra were analyzed by comparing the experimental measurements with the theoretical predictions of the SCO atomic physics code [4,5], based on the superconfiguration approximation [6].

Measurements of the absorption spectra of plasma mixtures are timely and important as they can provide benchmarks for recently developed theoretical models [7]. Such models are of particular interest especially in astrophysics

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where plasma mixtures dominate stellar behavior. The compound ZnS was chosen because the sulfur $n = 2-3$ and zinc $n = 3-4$ transitions, where $n$ is the principal quantum number, lie in the same spectral region and do not overlap. Finally, the Al study was performed because its absorption spectra have been previously measured [8,2] and as a low-Z element its absorption spectra can also be accurately predicted by detailed atomic physics codes such as HULLAC [9,10]. Thus, it provides an independent means of inferring the foil temperature achieved under the specific experimental conditions.

## 2. Experimental setup and methods

### 2.1. Experimental setup

The experiment was performed at the LULI2000 laser facility, where two frequency-doubled ($\lambda = 0.53$ μm), 500 ps pulse duration, Nd-glass laser beams were used. A schematic of the experimental setup is given in Fig. 1. The first beam, hereafter called the "main beam", heated the spherical gold cavity. It was focused with a $f = 800$ mm lens coupled with a random phase plate (RPP) to obtain a 500 μm diameter FWHM focal spot at the entrance hole of the cavity. The energy of the main beam at 0.53 μm wavelength was ~130 J giving an average intensity of $1.3 \times 10^{14}$ W/cm$^2$.

A 1.2 mm diameter spherical gold cavity was used for the radiative heating of the absorption foils. The main beam heated a 130 nm thick gold foil located at the entrance hole of the cavity (∅ 700 μm). The radiation emitted from the back side of this foil was absorbed by the wall of the cavity producing a plasma layer on its interior, which then emitted radiation that was confined in the cavity. An absorption foil placed on one of the two diagnostic holes (∅ 250 μm) was heated by the radiation emitted from the cavity and by the directly-irradiated Au foil.

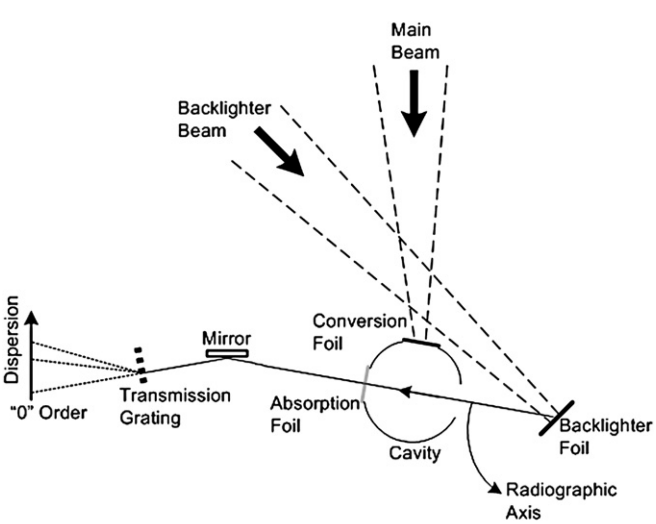


Fig. 1. Experimental setup for the absorption measurement of ZnS foils heated by the X-rays radiative emission of a gold cavity.

Two foils thicknesses were used: 48.9 nm or 97.8 nm for ZnS and 74 nm or 148 nm for Al, which correspond to 20 and 40 μg/cm$^2$ areal mass, respectively. The absorption foils of both types were coated on both sides with 35.3 nm thick carbon tampers corresponding to 8 μg/cm$^2$ areal mass. The tampered configuration was used to reduce the density and temperature gradients along the plasma expansion axis, and thus to improve the homogeneity of the probed plasma [11].

The second laser beam, delivering an energy of 30 J at 0.53 μm wavelength – hereafter called the "backlight beam", or BL beam – was focused on a 20 μm thick gold foil to produce a XUV absorption source, or backlight, used to probe the radiatively heated foils. The backlight producing gold foil was placed at a distance of 3 mm from the cavity to prevent the heating of the absorption foils. The BL beam was delayed by 800 ps with respect to the main beam. This delay ensures that the absorption probing occurs late enough to minimize the temperature gradient of the target plasma introduced by its hydrodynamic expansion, but early enough to prevent the plasma obscuring the line of sight along from the BL to the spectrometer defined by the cavity diagnostic holes (see Fig. 1). Furthermore, with this delay, the probing occurs when the radiative emission of the cavity is small, being on the order of the background level.

Both laser focal spots were monitored using two X-ray pinhole cameras. The backlight spectra were time-resolved using an XUV spectrograph coupled with a X-ray streak camera. The spectrograph was composed of a 2000 lines/mm gold transmission grating with a Ni spherical mirror with curvature radius 5200 mm. The mirror was placed with a grazing incidence angle of 6.4° to reject the energetic X-ray photons with wavelengths below 20 Å. Due to the spectrograph dispersion, the streak camera recorded photons up to 200 Å. Thus, the spectrograph covered the spectral range 20–200 Å with a resolution of 2.4 Å. The time resolution provided by the streak camera was 50 ps.

### 2.2. Backlighter spectrum characterization

Fig. 2 shows a raw time-resolved spectrum of a 20 μg/cm$^2$ Al absorption foil. The weak spectral feature emitted first corresponds to the self-emission of the cavity transmitted by the foil, while the second feature corresponds to the transmitted backlighter emission. The backlight spectra were obtained from the streak images with temporal average corresponding

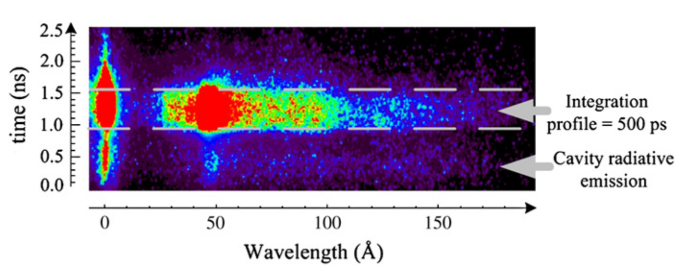


Fig. 2. Time-resolved Al XUV-absorption image recorded on the streak camera.