

## Multi-keV x-ray sources from HYBRID targets on GEKKO and OMEGA facilities

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**Abstract.** The feasibility of efficient X-ray sources for radiography on the LMJ (Laser MégaJoule) in the multi-kJ/ns range was demonstrated on the OMEGA laser facility (Univ. Rochester) from 2002 to 2004 [1, 2]. We significantly enhanced the conversion efficiency of titanium (4–6 keV), copper (8–10 keV) and germanium (9–13 keV) foils by using an optimized pre-pulse/pulse combination. Since higher X-ray energy and therefore electronic temperature need hydroconfinement, plastic cylindrical hohlraums internally coated with titanium, copper and germanium with various OMEGA beam configurations were successfully tested from 2005 to 2009 [3–5]. In addition, many shots with metal-doped aerogel (Ti, Fe, Ge) were tested on OMEGA [6].

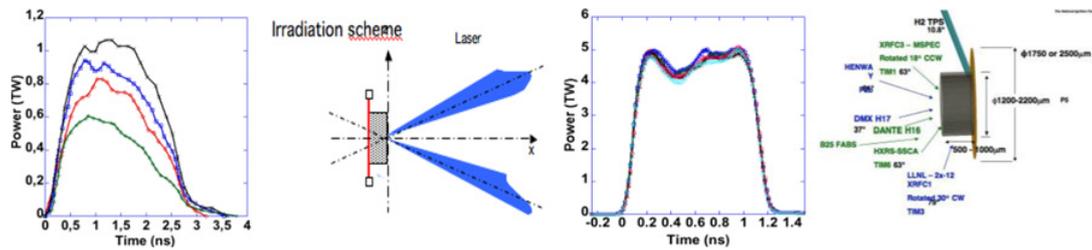
Recently we tested a new concept of “HYBRID sources” based on the combination of a thin titanium foil at the exit hole of a plastic cylinder filled with very low density SiO<sub>2</sub> aerogel (2 and 5 mg/cc). The benefit of the underdense medium is, first, to transport the laser energy to the titanium foil after its conversion into a supersonic ionization front and, second, to prevent foil expansion and excessive kinetic energy losses by longitudinal hydroconfinement.

### 1. INTRODUCTION

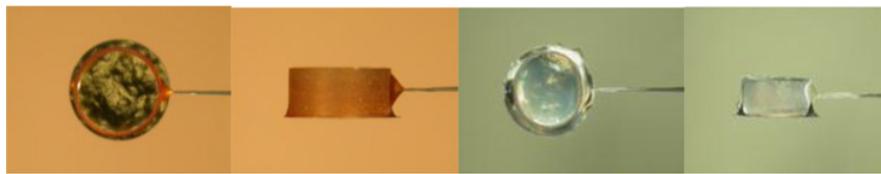
Development of bright emission sources in the multi-keV photon energy range is necessary for the radiography of dense materials on LMJ and NIF experiments. Accurate predictive simulations are requested to set up relevant X-ray sources to improve our knowledge about X-ray production from K-shell metallic targets. The goal is to explore the existing domain between solid metallic foils with low conversion efficiencies in the multi-keV range and the metal-doped aerogels with efficiencies limited by the low doping percentage of metallic atoms due to target fabrication constraints. The association of foil and aerogel resulted in the concept of HYBRID targets, partly validated during a campaign of three experiments. Measurements of a supersonic thermal wave propagation in the aerogel cylinder in addition to x-ray conversion efficiencies are of great interest for comparison with simulation. This is indeed a test of our code’s ability to deal with thermal transport in the low density medium along with non local thermodynamic equilibrium (NLTE) multi-keV x-ray emission.

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**Figure 1.** Two left pictures: laser incident powers (TW vs time in ns) for GEKKO XII shots and irradiation scheme. The same for OMEGA on the two right pictures.



**Figure 2.** Pictures of HYBRID targets: without aerogel (left) and with aerogel (right).

## 2. EXPERIMENTAL SET-UP: LASER CONDITIONS AT GEKKO XII AND OMEGA

The GEKKO XII facility used twelve beams for one side irradiation of the target located at the center of the HIPER chamber [7]. Three laser beams producing  $2\omega$  light (200 J/beam) and 9 beams converted at  $3\omega$  (150 J/beam) have been used to irradiate the HYBRID targets. The total energy was 2 kJ with pulse duration of 2.5 ns.

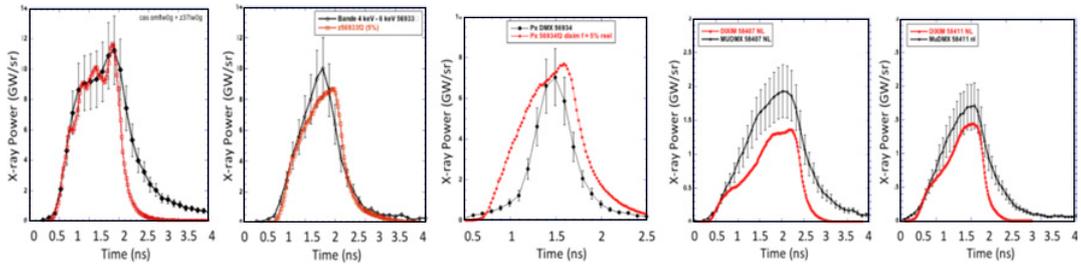
In the February experiment on the OMEGA facility, we used both  $21^\circ$  and  $42^\circ$  cones resulting in one side irradiation of about 5 kJ (1 ns duration) and in the June experiment we used only one cone at  $21^\circ$  for a total energy of about 2 kJ (2 ns duration).

## 3. TARGETS

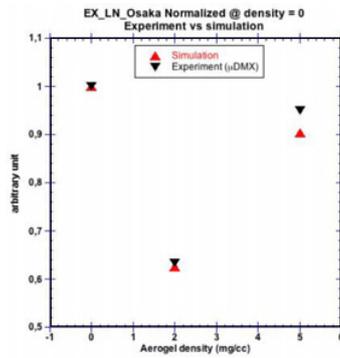
HYBRID targets are composed of a titanium foil (thickness:  $3\ \mu\text{m}$  or  $20\ \mu\text{m}$ ) located at the end of a plastic cylinder filled with a low density (2 and 5 mg/cc)  $\text{SiO}_2$  aerogel. Effects of the aerogel density have been considered as well by comparison with empty cylinders. Cylinders sizes are the following: 0.5 or 1 mm in length and 1 or 2 mm in diameter. Three combinations of target size have been built: SN-type for Short-Narrow, LN-type for Long-Narrow and LW-type for Long-Wide. Front and side pictures of the targets are displayed in Fig. 2.

## 4. DATA ANALYSIS

Conversion efficiencies (CEs) from HYBRID target emission have been monitored by the broadband absolutely calibrated CEA diode-based x-ray spectrometers, microDMX and DMX. CEs are defined as the ratio of x-ray energy emitted between 4 and 6 keV to the total incident laser energy. Powers versus time, given per solid angle unit in the direction of the diagnostic (in GW/sr), are displayed in Fig. 3. During these campaigns, we have been able to test the aerogel density influence on x-ray output (from 0 mg/cc (i.e. empty tube), 2 and 5 mg/cc). X-ray yields are lowered when an aerogel of 2 mg/cc is placed before the foil but a greater value is found for 5 mg/cc. Surprisingly, the lowest x-ray output is obtained for intermediate density. Secondly, we varied the cylinder size from 1 to 2 mm and the length from



**Figure 3.** Calculated X-ray powers superimposed with measured ones (from left to right: three shots in February and two shots in June).



**Figure 4.** Measured and calculated x-ray energies in 4–6 keV normalized to the value at 0 density.

0.5 to 1 mm: it appears that these targets produce similar multi-keV yields close to  $5 \times 10^{-3} J_X/J_L/\text{sr}$ , which represents, for 3  $\mu\text{m}$  thick target with quasi-isotropic emission, a CE of  $\approx 6.3\%$  in  $4\pi$ . Third, foil thickness variations (from 3 to 20  $\mu\text{m}$ ) show different trends between 2 and 5 mg/cc and x-ray emission is lower at 5 mg/cc.

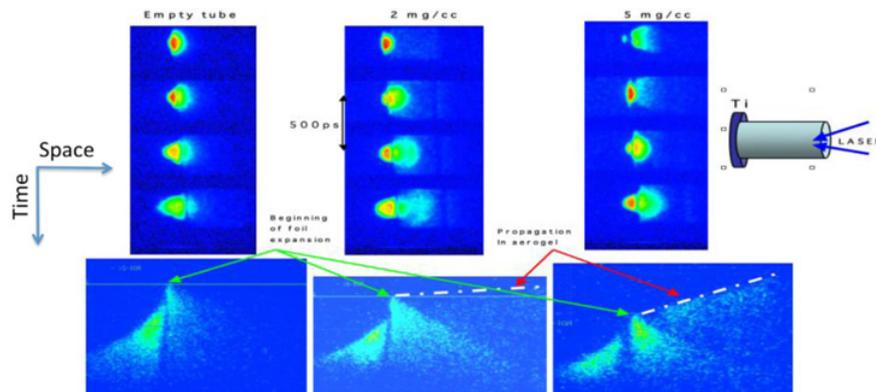
### 5. MULTI-KEV WAVEFORMS

We have shown on Fig. 3. the multi-keV emission power versus time for three OMEGA February shots and two June shots. The agreement is rather good for the February conditions (first three pictures from the left) and a little bit underestimated in June (two right pictures).

For GEKKO shots of LN-type targets we reproduced the qualitative behaviour of the x-ray energy with the aerogel density as shown in Fig. 4.

### 6. VELOCITY MEASUREMENT AT GEKKO XII

In addition, these experiments took great benefits from time and space resolved spectrometers from ILE laboratory. Images shown in Fig. 5. come from x-ray streaked camera diagnostic called XSC [8][9]. For an empty tube, first emission occurs when laser hits the foil from expanding plasma and a noticeable rear side emission is visible when laser beams have totally ablated the solid foil and it passed through. When aerogel is present, there is early times emission during laser propagation through the aerogel that is a signature of the ionization wave. This emission is followed by strong emission from titanium plasma expansion when laser has reached the foil. This rear side emission is stronger for 2 mg/cc since laser energy losses into the aerogel is weaker for such low aerogel density.



**Figure 5.** Space and time resolved images obtained from XSC diagnostic for an empty tube, 2 and 5 mg/cc aerogel densities. Cylinders are LW-type ( $L = 1 \text{ mm} = 2 \text{ mm}$ ) and titanium foil thickness is  $3 \mu\text{m}$ . The dash white points indicate the estimated velocity of the thermal wave in the aerogel. LW-type cylinders are shown as an example but the same features are observed with SN and LN-type targets.

These images allow propagation speed measurements of ionization wave through a low density medium. For S-N and L-N cylinder types filled with aerogel of 2 mg/cc in density, ionization wave passes through aerogel at a speed of about  $10^8 \text{ cm/s}$  (i.e.  $1000 \mu\text{m/ns}$ ). This propagation speed is decreased by 20–30% compared to 5 mg/cc. On the contrary, for a large diameter cylinder (LW type), the speed is more than two times higher than for other target sizes. Speed at 5 mg/cc is similar for all target sizes at about  $7 \times 10^7 \text{ cm/s}$  (i.e.  $700 \mu\text{m/ns}$ )[10].

## 7. CONCLUSION

These campaigns were a good opportunity to study the ability of our hydro-radiative code to deal with NLTE emission, radiation and thermal transport in underdense medium in the complex geometry of these HYBRID targets. Some discrepancies have been noted between the calculated and measured x-ray energies in the GEKKO shots. This could be partly explained by a crude modeling of the propagation velocity in the heterogeneous foam. At higher energy i.e. the February OMEGA shots, the qualitative and quantitative agreement is quite good. Explanations of these discrepancies are currently under study.

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