LLNL-JRNL-554314

LAWRENCE LIVERMORE NATIONAL LABORATORY

Source Geometric Considerations for OMEGA Dante Measurements

M. J. May, R. Patterson, C. Sorce, K. Widmann, K. Fournier, F. Perez

May 2, 2012

Review of Scientific Instruments

Source Geometric Considerations for OMEGA Dante Measurements[a]

M. J. May[1b], R. Patterson[1], C. Sorce[2], K. Widmann[1], K Fournier[1] and F. Perez[1]

[1]*Lawrence Livermore National Laboratory, Livermore, California 94551, USA.*
[2]*Laboratory for Laser Energetics, University of Rochester, 250 East River Road, Rochester, NY 14623.*

(Presented 5/XX/2012; received XXXXX; accepted XXXXX; published online XXXXX)
The Dante is a 15 channel filtered diode array which is installed on the OMEGA laser facility at the Laboratory for Laser Energetics, University of Rochester. The system yields the spectrally and temporally resolved radiation flux from 50 eV to 10 keV from various targets (i.e. hohlraum, gas pipes, etc.). The absolute flux is determined from the radiometric calibration of the X-ray diodes, filters and mirrors and an unfold algorithm applied to the recorded voltages from each channel. The unfold algorithm assumes an emitting source that is spatially uniform and has a constant area as a function of photon energy. The emitting X-ray source is usually considered to be the Laser Entrance Hole (LEH) of a given diameter for Hohlraum type targets or the effective wall area of high conversion efficiency K-shell type targets. This assumption can be problematic for several reasons. High intensity regions or 'hot spots' in the X-ray are observed where the drive laser beams strike the target. The 'hot spots' create non-uniform emission seen by the Dante. Additionally, thinned walled (50 μm) low-Z targets ($C_{22}H_{10}N_2O_5$) have an energy dependent source size since the target's walls will be fully opaque for low energies (E< 2-3 keV) yet fully transmissive at higher energies. Determining accurate yields can be challenging for these types of targets. Discussion and some analysis will be presented.

I. INTRODUCTION

The Dante[1] is an X-ray diagnostic that is routinely used during laser produced plasma experiments to measure spectrally and temporally resolved absolute X-ray flux. The X-ray flux measurements are used to deduce radiation temperatures, T_r, and X-ray conversion efficiencies, etc. from various laser targets (e.g. gold hohlraums, gas pipes, backlighter foils etc.). The measurements from a Dante are critical in the understanding yields from bright X-ray targets[2] used for backlighting and material damage studies. Dante systems are in operation on both the OMEGA[3] laser facility at the Laboratory for Laser Energetics, University of Rochester and the National Ignition Facility[4] (NIF) at the Lawrence Livermore National Laboratory. A similar system, DMX[5], is operated by the French Atomic Energy Agency (CEA).

The Dante at the OMEGA Laser facility consists of 15 channels filtered for the X-ray spectral region. The radiation from a target is recorded in discrete broad spectral bands between 50 eV to 10 keV with temporal resolutions of 100 - 200 ps. The resolution (E/ΔE) of the DANTE is < 10. Each channel consists of a different set of X-ray filters, mirror and X-ray diode (XRD) optimized to measure a given spectral region. Absolute flux measurements are possible since all components are absolutely calibrated, and the geometry of the system is known. Details of the standard configuration are presented in Ref 2.

The spectra and total X-ray flux from a given target are determined from the channel voltages by using a spectral reconstruction algorithm, typically called an unfold, and the photometric response functions of each channel. Different algorithms[6] exist for unfolding the spectra from the recorded voltages from the XRDs. However, each of the unfold algorithms assumes that the source is spatially uniform with known size to determine the absolute measured spectral flux, target yield or radiation temperature. For Hohlraums this is considered to be a uniformly emitting laser entrance hole (LEH). For bright X-ray sources the target is assumed to be emitting uniformly. For both types of targets, high emission regions or 'hot spots' have been observed in images filtered for the X-rays with views similar to that of the Dante. These 'hot spot' regions are typically at the deposition region of the drive laser beams and make the emitting source inherently not uniform.

Also, bright K-shell targets typically use low Z (CH), thin walled (~50 μm thick) tubes to allow the X-ray emission to penetrate and to make the target useful as a radiation source. As a result, the K-shell emission is isotropic, but the softer energy radiation, less than 2-3 keV, is emitted from just the LEHs on the ends of the target since the target walls are opaque to the lower photon energies. Therefore, these bright X-ray targets have an effective emitting source area that is energy dependent. This has been confirmed with images filtered in different X-ray spectral bands. In contrast, a Hohlraum's emitting region is just the LEH below < 10 keV since typical a Hohlraum has a gold wall thickness of greater than 25 μm. The gold is opaque to all but the gold L- or K-shell emission.

Flux and radiation temperature measurements for the Hohlraum can be determined by assuming an emitting source with a constant area. For a bright X-ray targets, this assumption is not true. The variations in the emitting source area with energy must be corrected for in order to accurately determine the flux from a given laser produced plasma target. In this paper, these corrections to the emitting area as a function of photon energy and their effect on the targets yields are discussed in detail for bright X-ray type targets.

[a])Contributed paper published as part of the Proceedings of the 19th Topical Conference on High-Temperature Plasma Diagnostics, Monterey, California, May, 2012.
[b])Author to whom correspondence should be addressed. Electronic mail: may13@llnl.gov

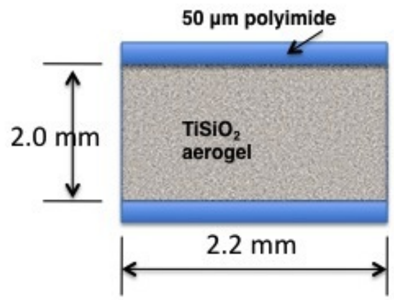

Figure 1: Drawing of a typical $TiSiO_2$ aerogel X-ray target.

II. DANTE UNFOLD ALGORITHM AND EMITTING AREA PHOTON ENERGY DEPENDENCIES

The traditional algorithm[6] for unfolding a spectrum at a given time from the recorded Dante voltages is the one currently used at both the OMEGA and the NIF laser facilities. The voltages recorded by each of the channels are a function of the emitted X-ray spectrum and the photometric channel response. The voltage, V_i, in each channel, i, can be mathematically expressed as:

$$V_i = P_i\Omega_i \int_0^\infty R_i(E)S(E)A\cos(\theta)dE \qquad (1)$$

Here, Ω_i is the solid angle of each channel, and $R_i(E)$ is the response function of each Dante channel. P_i is the electrical attenuation in each channel. E is the photon energy. θ is the angle between the Dante and the normal to the emitting surface. The spectrum S(E) is the unknown and is to be unfolded from the channel photometric response functions and the recorded voltages. The reconstructed spectrum is inversely proportional to the area of the emitting source, A, for a given voltage. The traditional algorithm uses a spectrum of the form of blackbody corrected by Gaussians. The total X-ray flux, F, is the integral of the spectrum. The radiation temperature, T_r, is determined from $F = A\cos(\theta)\,\sigma\, T_r^4$.

The traditional spectral unfold algorithm assumes a uniform source with a well defined and constant X-ray emission area as a function of energy for these bright X-ray source targets. To determine a more accurate unfolded spectrum, we will assume that projected area (Acos(θ)) is now an effective area $A_{eff}(E)$ and a function of photon energy. $A_{eff}(E)$ must be included in the integral of the spectral unfolding algorithm. The emitting area will take the form of

$$A_{Eff}(E) = \left[A_{LEH}\cos(\theta)\right]\left[1 + T(E)\left(\frac{A_{WALL}\sin(\theta)}{A_{LEH}\cos(\theta)}\right)\right] \quad (2)$$

for the cylindrical target shown in Figure 1. T(E) is the transmission of the material of the target wall along the line of sight of the Dante. A_{LEH} and A_{Wall} are the areas of the end of the tube and the area of the wall, respectively. At low photon energies the emitting area reduces to just the LEH area.

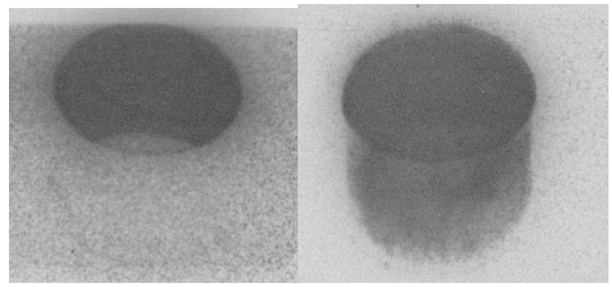

Figure 2: Framing camera images from the $TiSiO_2$ aerogel target at 1.2 ns. The image on the left is filtered for ~ 250 eV light with 5 μm of Parylene and a 3° Al mirror and shows just the LEH emission. The right image is filtered for > 1 keV light with 25 μm of Be and shows X-ray emission from the entire target.

III. TARGETS AND X-RAY IMAGES

The emission from bright X-ray targets has been investigated using the Omega laser for the past 5 to 10 years. These target yields have been routinely determined from the Dante measurements. Recently targets with low density (6 - 50 mg/cc) Fe and Ti aerogel targets have been irradiated with ~20 kJ from 40 beams of the Omega laser. The targets were mounted along either the P6-P7 or P5-P8 axis. A drawing of a sample target is shown in Figure #1. The target is a 2.0 mm in diameter 2.2 mm in length polyimide ($C_{22}H_{10}N_2O_5$) tube with a 50 μm thick wall containing an aerogel or a stainless steel coating[7].

These targets have been imaged with gated framing cameras that have been filtered in several different bands in the X-ray. Sample images are shown in Figure #2 that were taken at the peak of the emission for a $TiSiO_2$ aerogel target at 1.2 ns after the start of the laser pulse. The view of the camera is 37° from the cylindrical axis of the target and very similar to the view of the Dante. The image on the left is filtered for ~ 250 eV light with 5 μm of Parylene and a 3° Al mirror. Additionally the target was imaged in 500 eV X-rays with a 1 μm thick V filter and a 3° Al mirror (not shown). The emission in the left image is from the Ti L-shell. Only the LEH is emitting since the Ti L-shell is significantly absorbed by the polyimide tube.

The right image in Figure #2 is filtered for > 1 keV light with 25 μm of Be. This image shows that the entire target is emitting at the higher X-ray photon energies which is mainly from the Ti K-shell lines. The target wall and the LEH have fairly uniform emission. The LEH is slightly brighter than the wall emission since the polyimide wall does attenuate the Ti K-shell slightly. These images demonstrate that the emitting area of the target changes significantly as a function of the energy of the emitted photon. Assuming an emitting source area that is constant as a function of photon energy will produce a less accurate yield in the K-shell. The Dante spectral unfold needs to account for this change in the effective emitting area.

For the example target the area of the LEH as viewed by the Dante can be expressed as

$$A_{LEH} = \pi r^2\cos(\theta) = 2.49\ \text{mm}^2 \qquad (3)$$

The variable r is the radius of the LEH and theta is the angle between the cylindrical axis of the target and the Dante view, 37.37°. The wall area as viewed by the Dante can be expressed as:

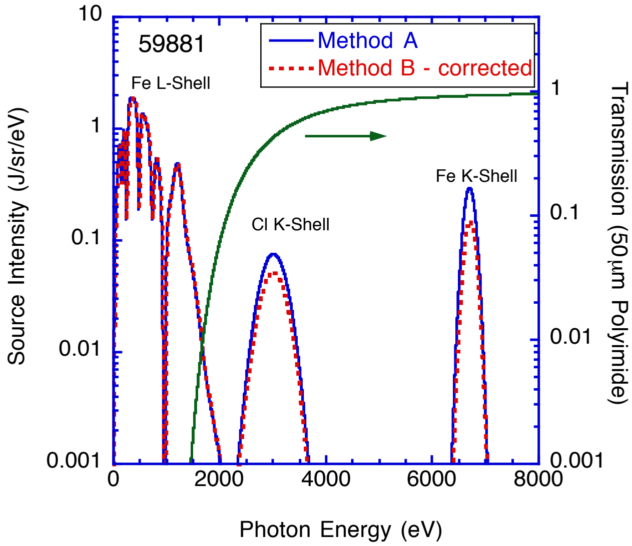

Figure 3: Total spectrum from the Dante unfold algorithm with and without emitting source area corrections at high photon energies. The target is comprised of $FeO_2HCl_{0.38}$ aerogel. The transmission of 50 µm of Polyimide is over plotted.

$$A_{Wall} = 2*r*L*\sin(\theta) = 2.64\ mm^2 \qquad (4)$$

L is the length of the target. The sum of the wall and LEH area is 5.14 mm^2. For these targets the emitting source area at high energy is roughly twice the area at low energy.

IV. DANTE YIELDS

The yields of three targets, an Fe aerogel (FeO_2 $HCl_{0.38}$), stainless steel lined cavity and a Ti aerogel target, were determined using the Dante and the traditional spectral unfold algorithm. Three different determinations of the unfolded spectra and yields are presented for these targets (see Figure #3 and Table #1). Method A assumes that the target emits from the LEH and is independent of the energy of the photon. Method B uses an emitting area of the target that has an energy dependency derived from Eq. 2, 3 and 4. Method B solely processes the effective emitting source area in the Dante unfold code. Method C takes the spectrum after the unfold algorithm using Method A and in post processing applies the emitting area corrections.

The unfolded spectra from the iron aerogel is presented in Figure #3. The blue trace is from Method A assuming a constant emitting area with photon energy. The red dashed line is from Method B. The transmission of 50 µm of Polyimide is over plotted in green. As expected the lower energy portion of the spectrum is the same for both method A and B. The LEH is the source of the emission since the transmission of the tube wall is very small. As the plastic tube transmission increases at higher photon energy, the emitting source size increases and the source intensity drops. At the Fe K-shell peak between 6.5 - 7 keV, the source intensity calculated by Method B is about a factor of ~2 less than that from Method A.

Target	Stainless Steel Cavity	Fe Aerogel (FeO_2 $HCl_{0.38}$)	Ti Aerogel (Ti doped SiO_2)
Omega Shot Number	59877	59881	64481
Laser Energy (J)	19607.0	19616.0	19092.8
He-like ($1s2p_{3/2}\rightarrow 1s^2$) (keV)	6.973	6.973	4.977
Method A: Yield K-Shell (No Energy Dependent Source Size) (J/sr)	46.6	74.2	41.3
Method B: Yield K-Shell (Energy Dependent Source Size) (J/sr)	23.9	41.6	26.0
Method C: Yield K-Shell (Post Process Energy Dependent Source Size) (J/sr)	23.9	41.6	25.9

Table 1: Summary of K-shell yields for several targets with and without corrections for the photon energy dependent emitting source size.

The total K-shell yields are given in Table 1 for the stainless steel cavity, the iron aerogel and the Ti doped SiO_2 aerogel targets. The yields computed by method B and method C are equivalent. This implies that correcting the spectra after the unfold algorithm is nominally equivalent to a correction during the unfolds with the traditional algorithm. The total yields for the iron K shell are reduced by about a factor of two when the correct source size is incorporated in the spectral unfold algorithm. The Ti K-shell yields are reduced by about a factor of 1.5. These changes in the estimated yields at high photon energy are significant for thin walled bright X-ray targets and must be accounted for, to produce an accurate yield estimation.

V. ACKNOWLEDGEMENTS

This work was done under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

VI. REFERENCES

[1] H.N. Komblum, R.L. Kauffmann, and J.A. Smith, Rev. Sci. Instrum. **57,** 2179 (1986).
[2] K. B. Fournier *et al*., Phys. Rev. Lett. **92**, 165005 (2004).
[3] C. Sorce *et al*., Rev. Sci. Instrum. **77**, 10E518 (2006).
[4] E. L. Dewald, Rev. Sci. Instrum. **75**, 3759 (2004).
[5] J.P. Bourgade *et al*., Rev. Sci. Instrum. **72**, 1173 (2001).
[6] A. Seifter et al, Rev. Sci. Instrum. **79**, 10F323 (2008).
[7] F. Perez, et al., Phys. Plasmas, in prep (2012).