Measurements of Heat Propagation in Compressed Shells in Direct-Drive Spherical Implosions on OMEGA

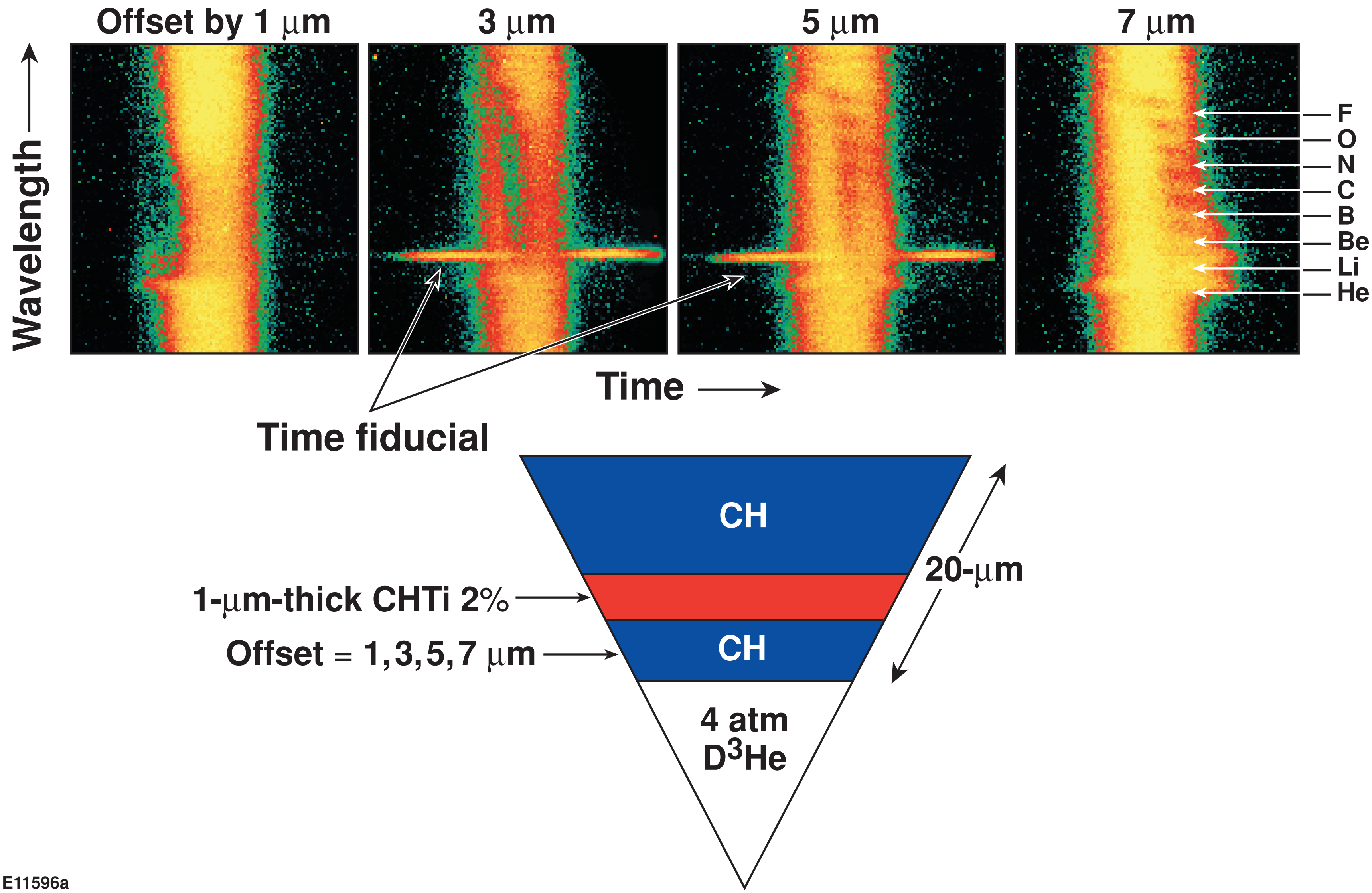
V. A. SMALYUK, J. A. DELETTREZ, S. P. REGAN, and B. YAAKOBI

University of Rochester
Laboratory for Laser Energetics

D. L. McCROREY and R. C. MANCINI

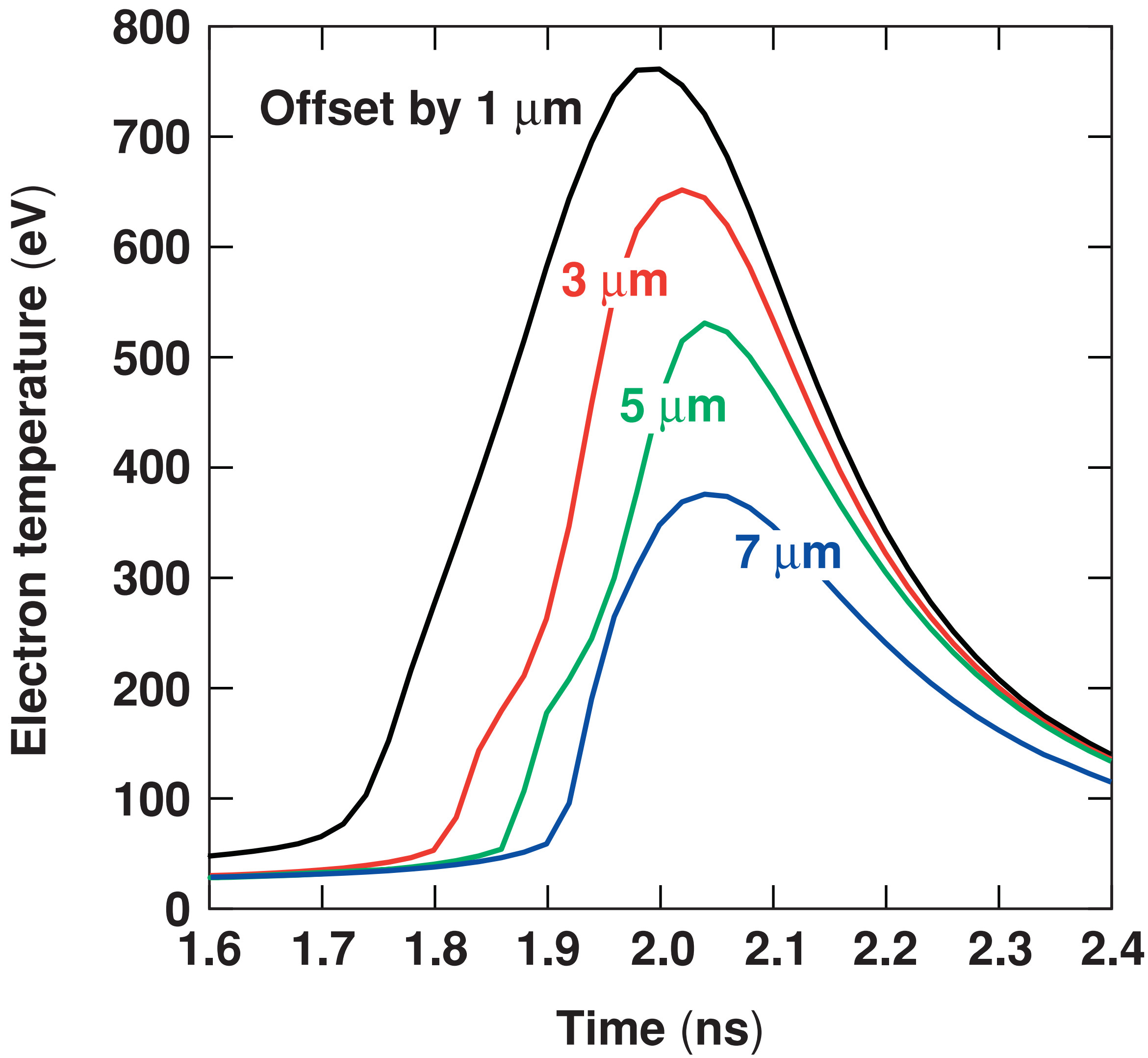
Department of Physics
University of Nevada, Reno

Shell temperature density and areal density is measured with 1s-2p absorption in titanium-doped layers



E11596a

LILAC predicts heat wave propagating through the shell



K-shell absorption depends on plasma temperature, density, and areal density

- The optical depth is written as

Oscillator strength

Ion fraction

$$\tau_\nu = \frac{\pi e^2}{mc}\left(\sum_{I,\,j} \bar{f}_{ij}\,\varphi_\nu^{(ij)} F_i\right) N\Delta R,$$

Line profile

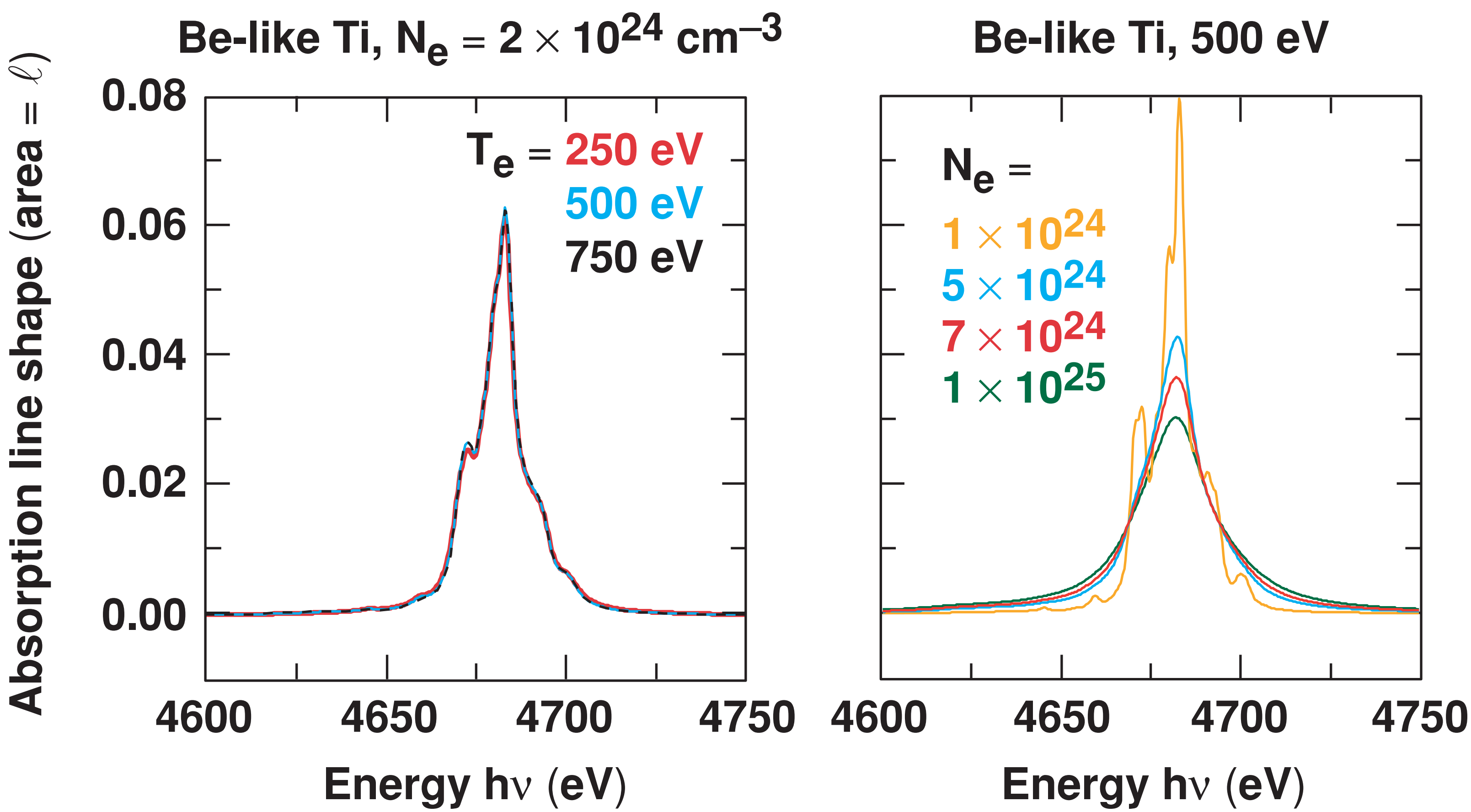
Proportional to areal density

and the transmission through a uniform absorbing layer is modeled according to

$$I_\nu = I_0 e \tau_\nu.$$

- Approximation: neglect self-emmision of the line.

At high densities (above 10^{24} cm^{-3}), the temperature sensitivity of the line shapes is weak

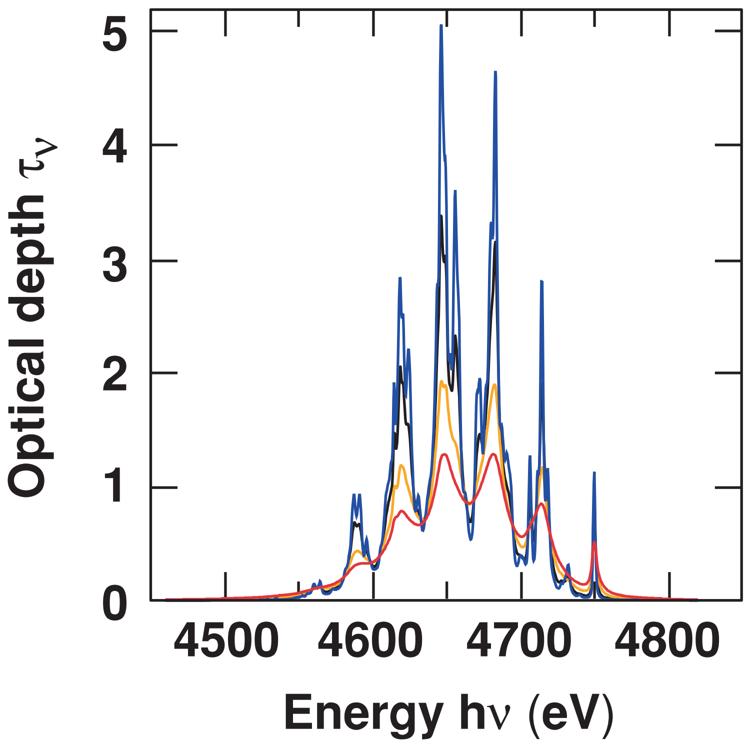


- For these high densities, Stark broadening becomes the dominant broadening mechanism, and the associated N_e dependence is a useful diagnostic tool.

E11774

The shape of the absorption spectrum depends strongly on density

- The density sensitivity of the optical depth, due ONLY to the density dependence of the Stark-broadened line shapes, is illustrated here for a sequence of increasing temperatures and densities that keep the ionization balance approximately constant.

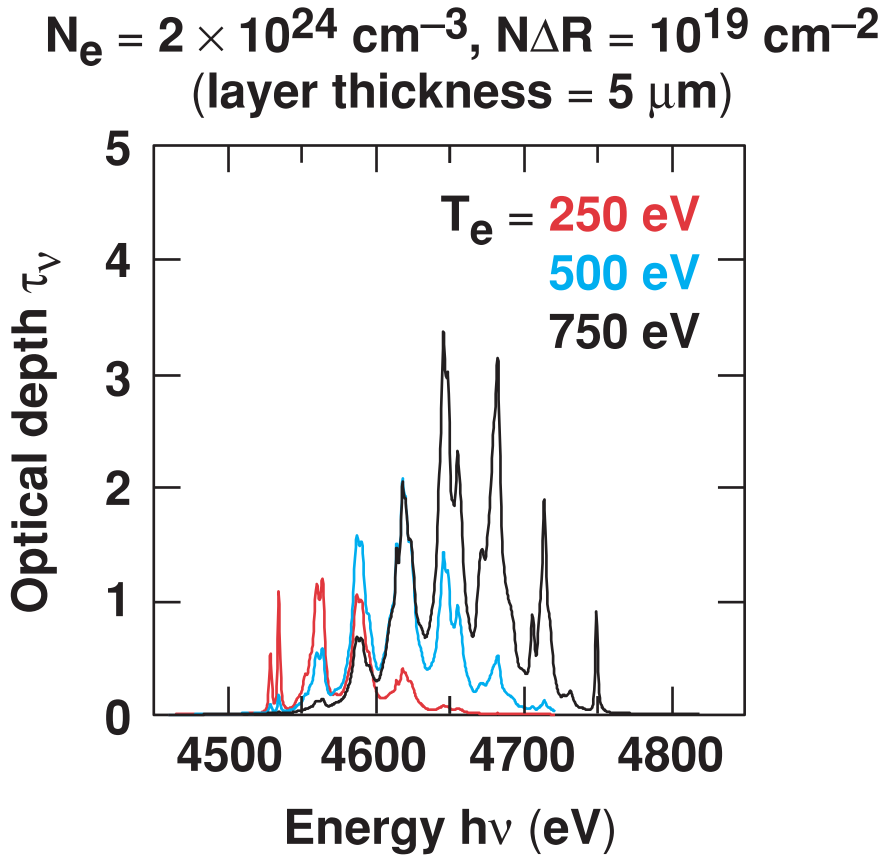


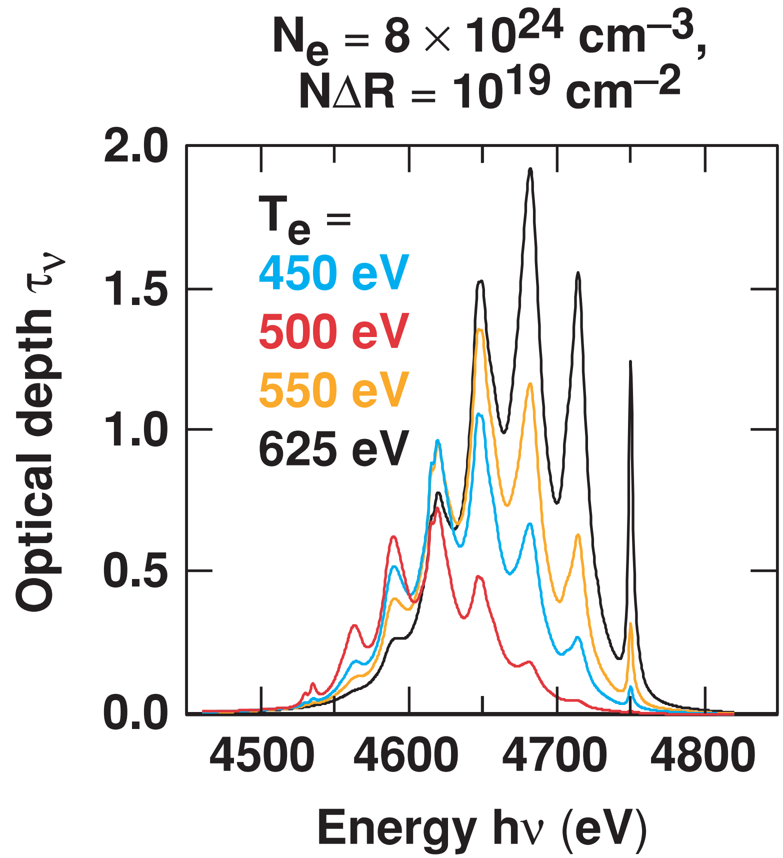
$N\Delta R = 10^{19}\ cm^{-2}$

$N_e = 1 \times 10^{24}\ cm^{-3}$, $T_e = 345$ eV ; $N_e = 5 \times 10^{24}\ cm^{-3}$, $T_e = 505$ eV
$N_e = 2 \times 10^{24}\ cm^{-3}$, $T_e = 400$ eV ; $N_e = 1 \times 10^{25}\ cm^{-3}$, $T_e = 620$ eV

E11776

The absorption spectrum shifts to higher photon energies with increasing electron temperature



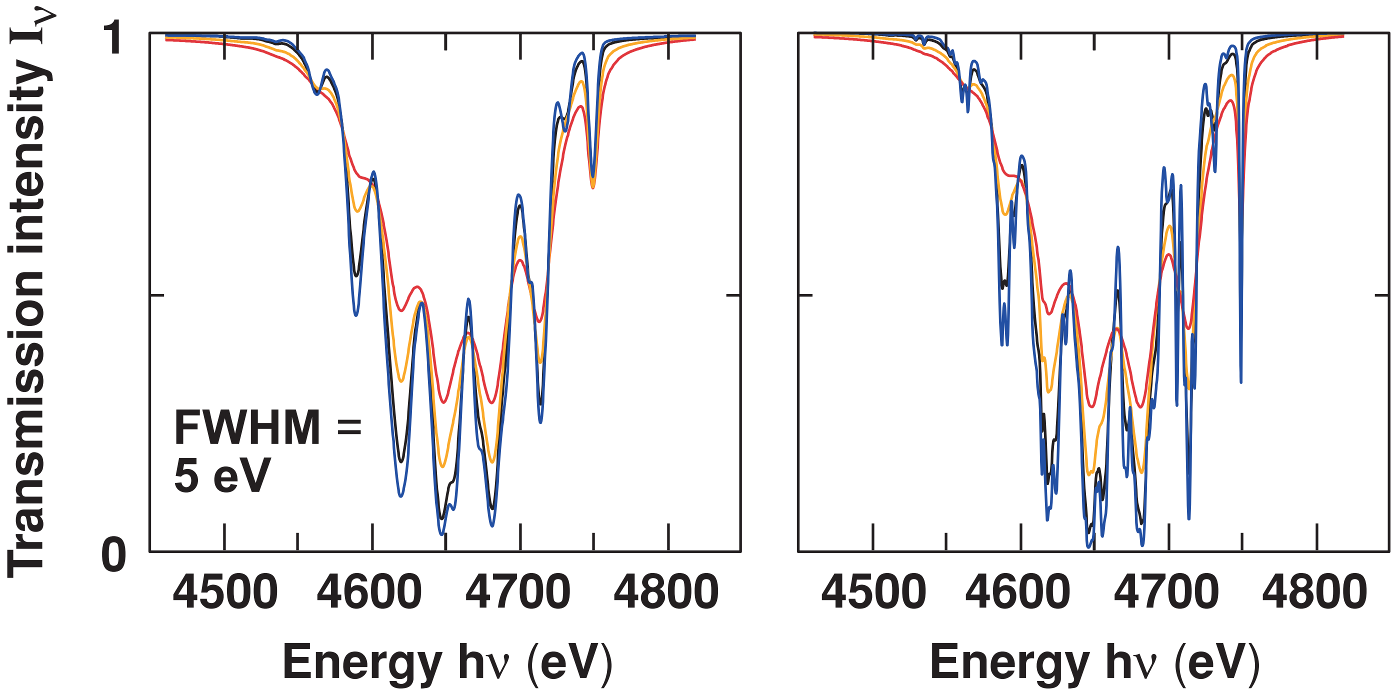


- The temperature sensitivity inherent in the level population kinetics results in a shifting of the ionization balance within the absorbing layer as T_e increases, and an associated change in τ_ν.

E11775

High spectral resolution is necessary to observe the fine structure of *K*-shell absorption

- The calculated line shapes are convolved with a Gaussian line profile to simulate the effect of instrumental broadening.



$N_e = 1 \times 10^{24}$ cm^{-3}, $T_e = 345$ eV ; $N_e = 5 \times 10^{24}$ cm^{-3}, $T_e = 505$ eV
$N_e = 2 \times 10^{24}$ cm^{-3}, $T_e = 400$ eV ; $N_e = 1 \times 10^{25}$ cm^{-3}, $T_e = 620$ eV

- The density sensitivity of I_ν persists when instrumental broadening is included in the model.

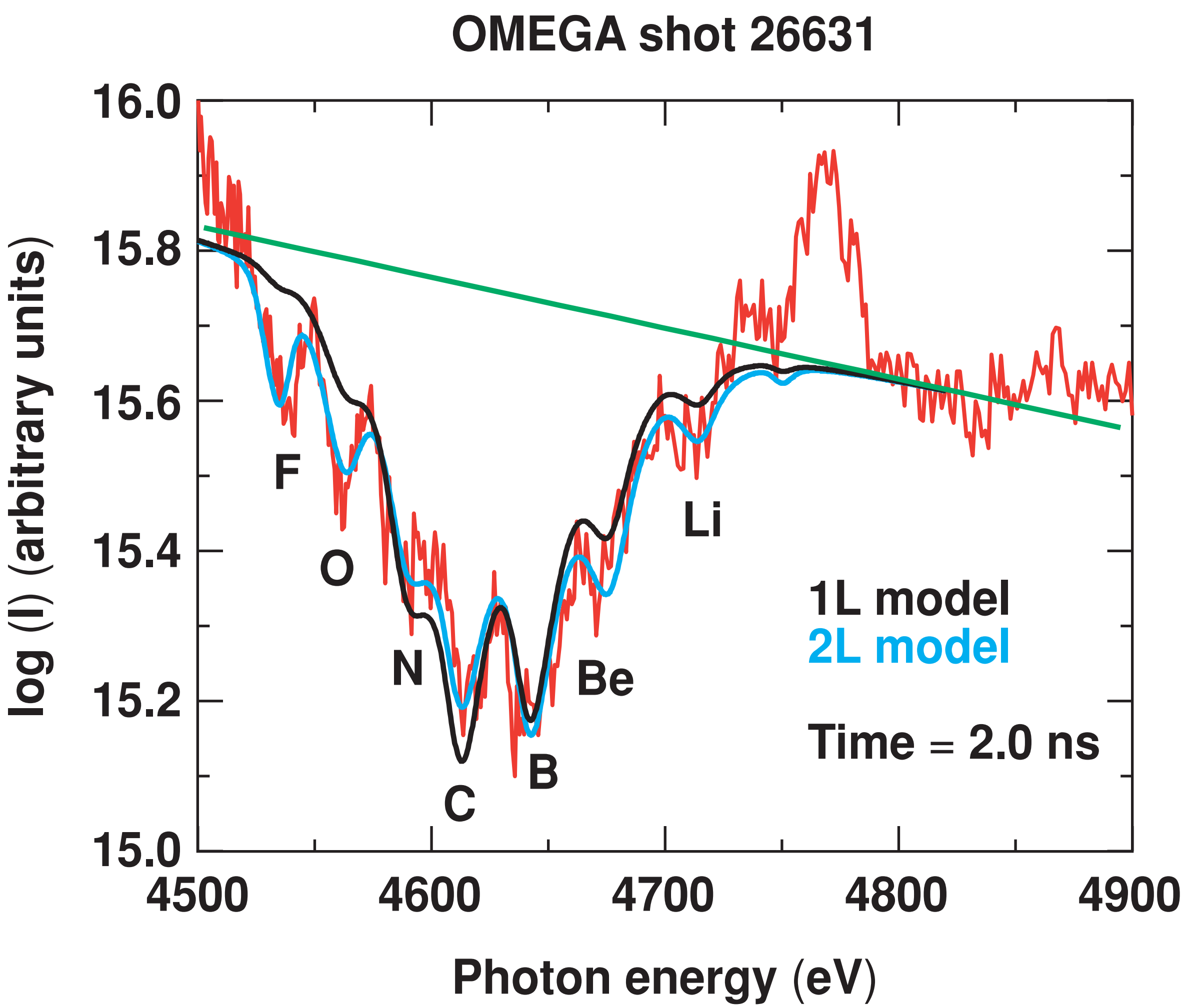
In experiments, 20-μm-thick shells are imploded with the OMEGA laser system

- Direct-drive implosions, 60 beams, 23-kJ UV energy, 1-ns square pulse
- Plastic shells of 1-mm diameter and 20-μm wall thickness, filled with 4 and 18 atm of D ^{3}He
- Ti-doped (2% by atom) plastic tracer layer, 1 μm thick, placed at 1, 3, 5, 7, and 9 μm from the inner surface of the shell
- Time-resolved Ti *K*-shell line absorption spectra recorded with streaked crystal spectrometer
- Spectral resolution ~ 7 eV

Absorption is analyzed using a single- or double-layer model; within each layer, uniform conditions are assumed

- For a double-layer model effective temperature and density conditions are computed with a NΔR-weighted average of each layer's values, and the total NΔR is the sum of individual values for each layer.
- NΔR values from the analysis refer to the areal density of the Ti dopant.
- Results are illustrated for OMEGA shot 26631, lineouts 1, 2, 3, and 4.
- For these lineouts, the temperature monotonically increases, while the density remains high and shows little change. NΔR initially increases and then drops.
- Late in time, an emission feature begins to cut into the absorption spectrum (lineout 4). The effect is more pronounced at even later times (i.e., lineouts 5 and 6).

At later times, the temperature increases



2L model:

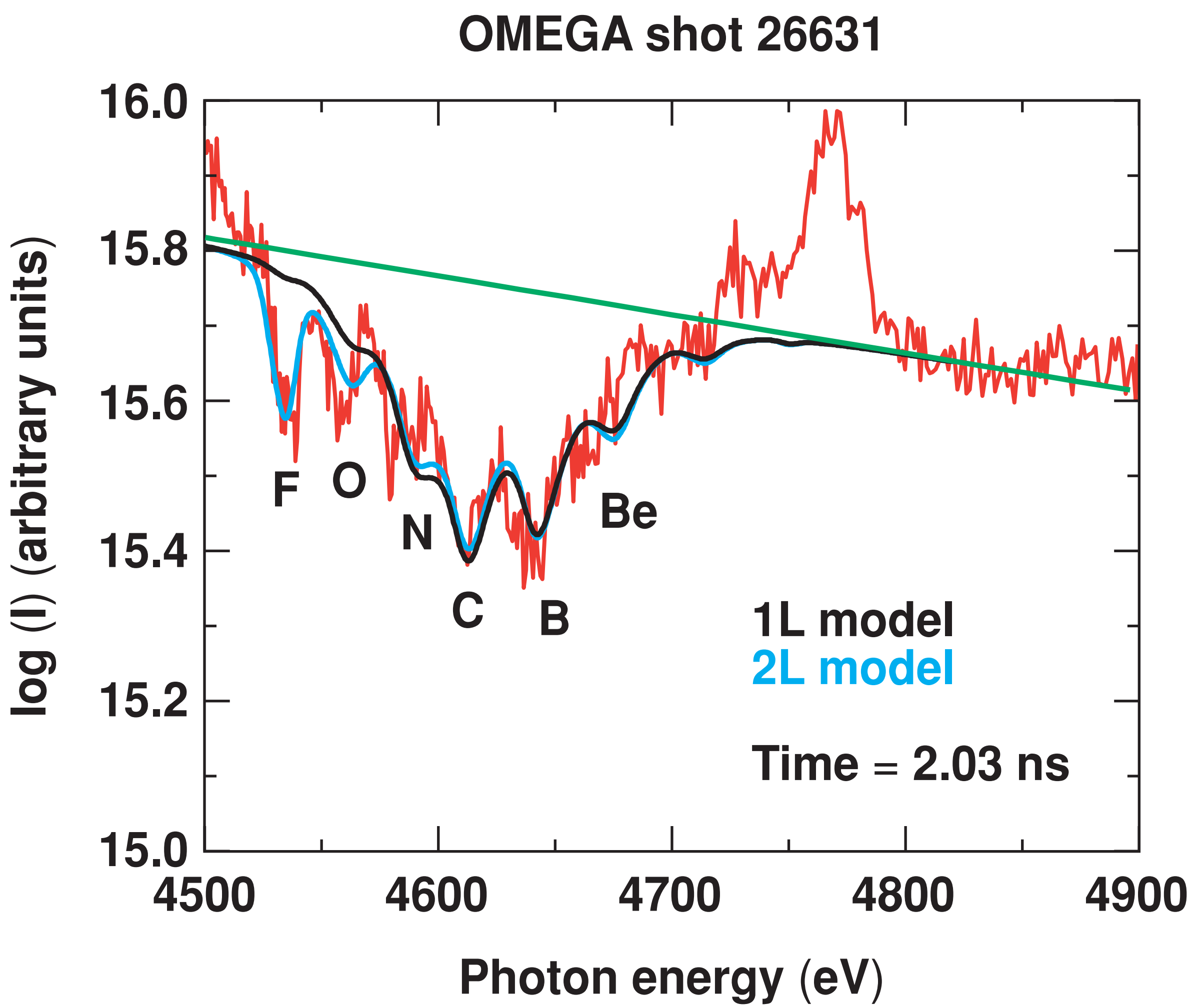
T_e = 410 eV

$N_e = 9.3 \times 10^{24}$ cm^{-3}

$N\Delta R = 2.9 \times 10^{19}$ cm^{-2}

E11781

At early times, outer-shell temperature is low (~ 300 eV)



2L model:

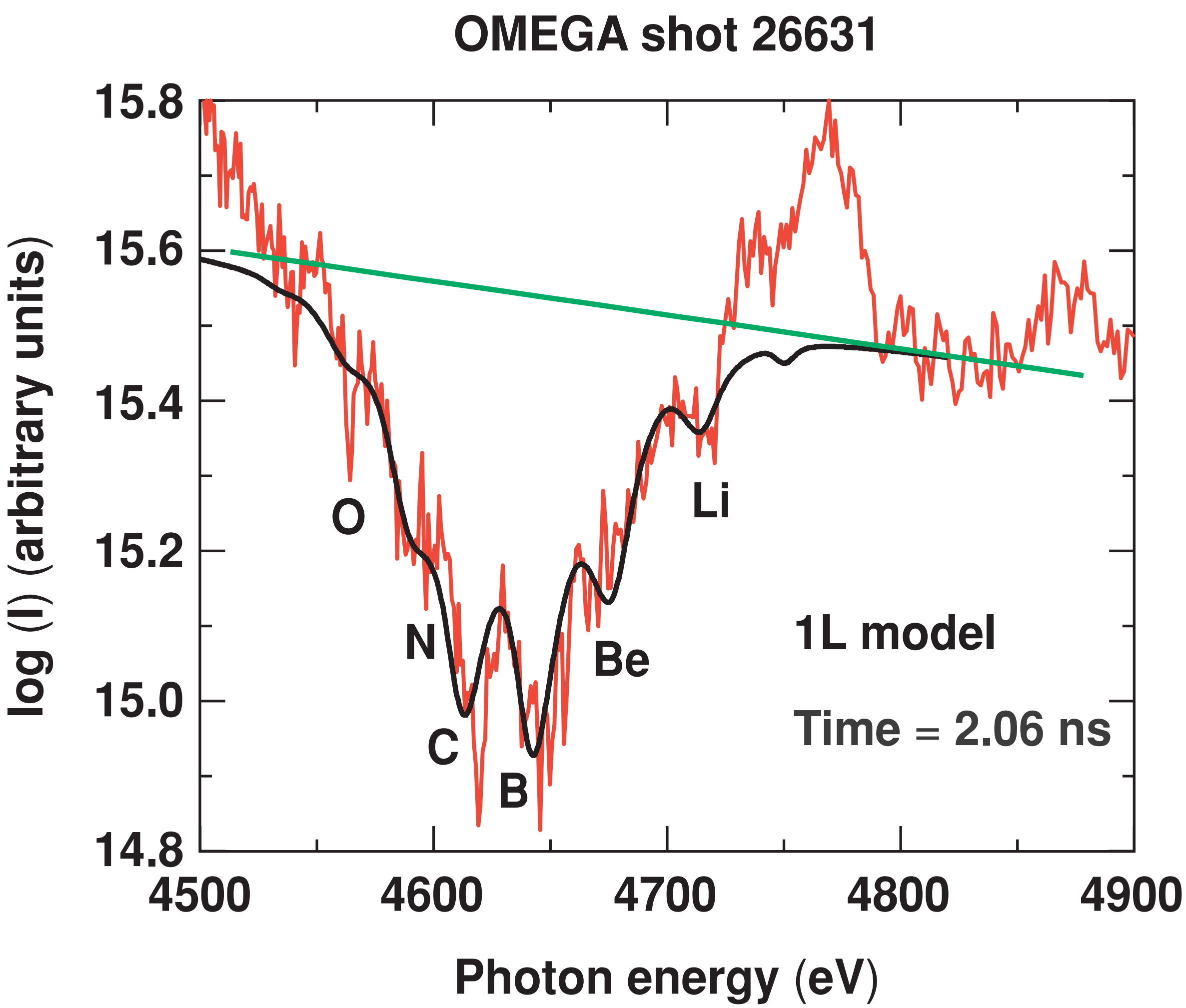
T_e = 325 eV

$N_e = 8.4 \times 10^{24}$ cm^{-3}

$N\Delta R = 2.6 \times 10^{19}$ cm^{-2}

E11780

Density and areal density in the layers are increasing up to the time of peak compression



1L model:

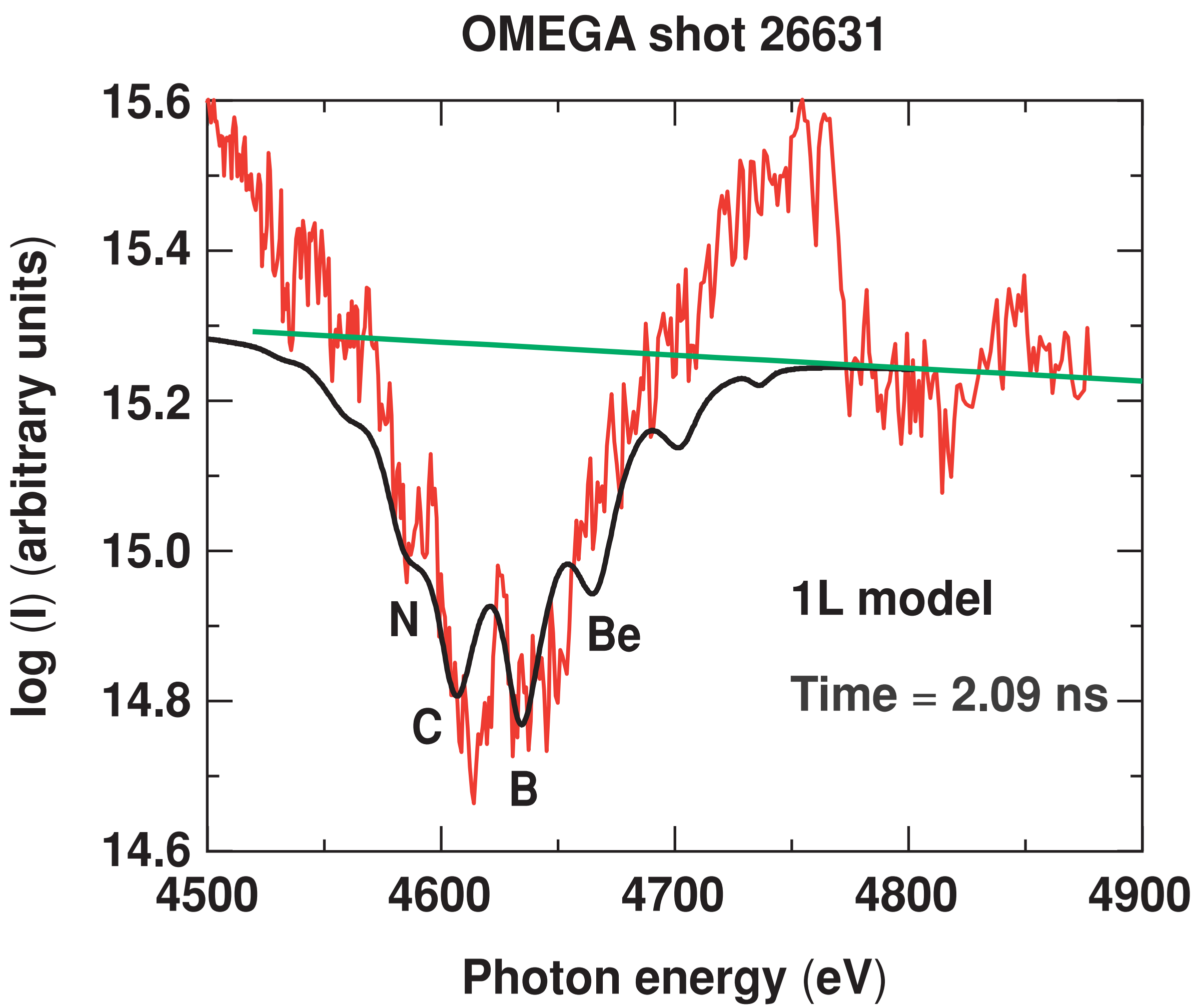
T_e = 530 eV

$N_e = 1.0 \times 10^{25}$ cm^{-3}

$N\Delta R = 1.6 \times 10^{19}$ cm^{-2}

E11783

At later times, the areal density drops while the temperature is constant



1L model:

T_e = 530 eV

$N_e = 1.0 \times 10^{25}$ cm^{-3}

$N\Delta R = 1.3 \times 10^{19}$ cm^{-2}

E11782

Summary

- For electron densities larger than 1×10^{24} cm^{-3}, the broadening of the Ti *K*-shell absorption lines is dominated by the Stark effect.
- This effect, combined with the temperature and density dependence of the level populations, results in an optical depth that is density and temperature dependent.
- Hence, detailed analysis of the absorption line spectra from Ti-doped tracer layers can be used to extract information about the state of the compressed pusher.
- Preliminary results from the analysis of data recorded in a series of OMEGA direct drive implosions are encouraging, showing heat-wave propagation through the shell.