Properties of the Blowoff Plasma Emitted from the Ends of a Cylindrical Dynamic Hohlraum*

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Radiation Hydrodynamics

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Objectives

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- To diagnose the properties of the blowoff plasma which arises from the ends of cylindrical dynamic hohlraums imploded by nested tungsten wire arrays on Z.
- To compare blowoff plasma conditions with those of the interior of the hohlraum.
- To assess the effects, if any, that the blowoff plasma has on the axial radiation from the hohlraum.

Approach: Tracer spectroscopy and radiation hydrodynamics calculations.

Dynamic hohlraum experiments on Z

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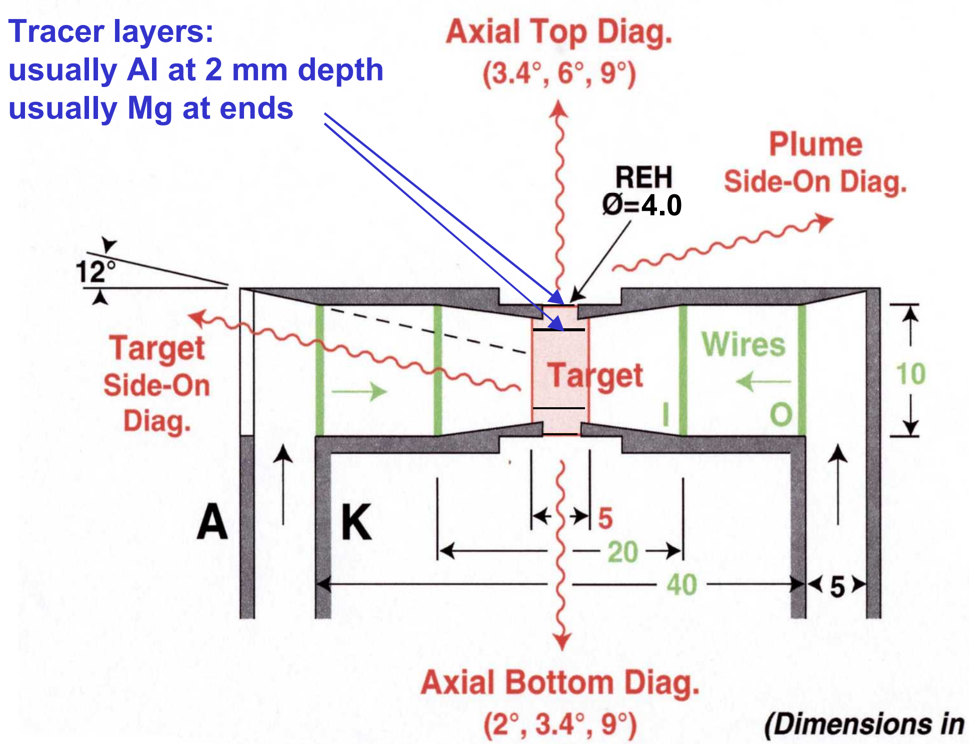
Two nested arrays of tungsten wires are imploded by 20 MA onto a cylindrical CH_2 foam target containing embedded Al and/or Mg tracer layers.



Diagnostics include:
time-resolving and time-integrating x-ray spectrometers, filtered XRD's and PCD's, bolo-meters, fast-framing pinhole cameras.

Typical experimental parameters

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Wire arrays: 120 wires at r =10 mm, 240 at 20 mm, mass 3 mg

Target: CH_2 foam, 14 mg/cc, 8-10 mm length, 5 mm diameter, mass 3 mg

Tracers: At ends or 2 mm deep, 0.3 μm Al, and/or 0.6 μm MgF_2

Implosion time: ~112 ns

Peak radial x-ray power (“stagnation”): ~140 TW for ~ 3 ns FWHM

Peak axial x-ray power: ~ 10-15 TW for ~ 4-5 ns FWHM, ~ 3 ns before stagnation

Wire-target collision: occurs about 6 ns prior to stagnation

Outer-inner array collision: about 22 ns prior to stagnation

Physical basis of diagnostics

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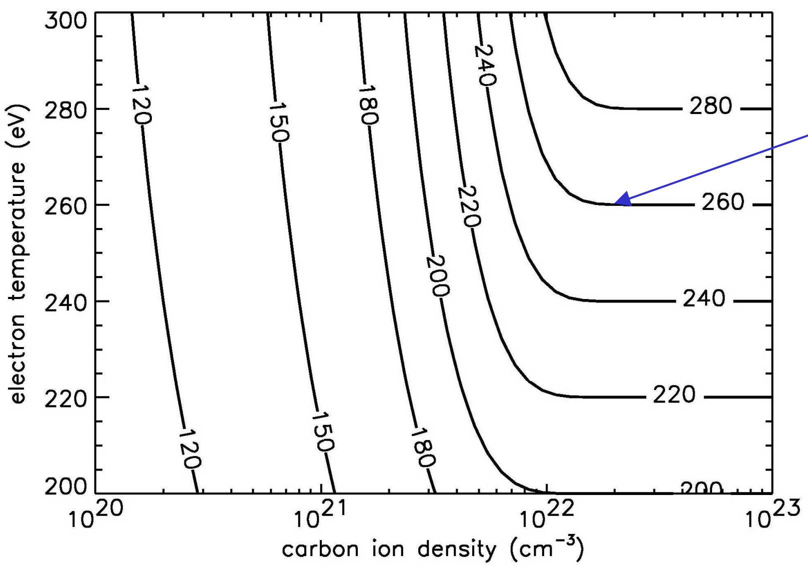
- **The tracer ionization stages are functions of both the electron and radiation temperatures.**
- **Compression of the target increases the density of the background carbon ions, producing a Planckian spectrum in which $T_{rad} \sim T_e$.**



Contours are the calculated radiation temperature for an 8 mm column of carbon

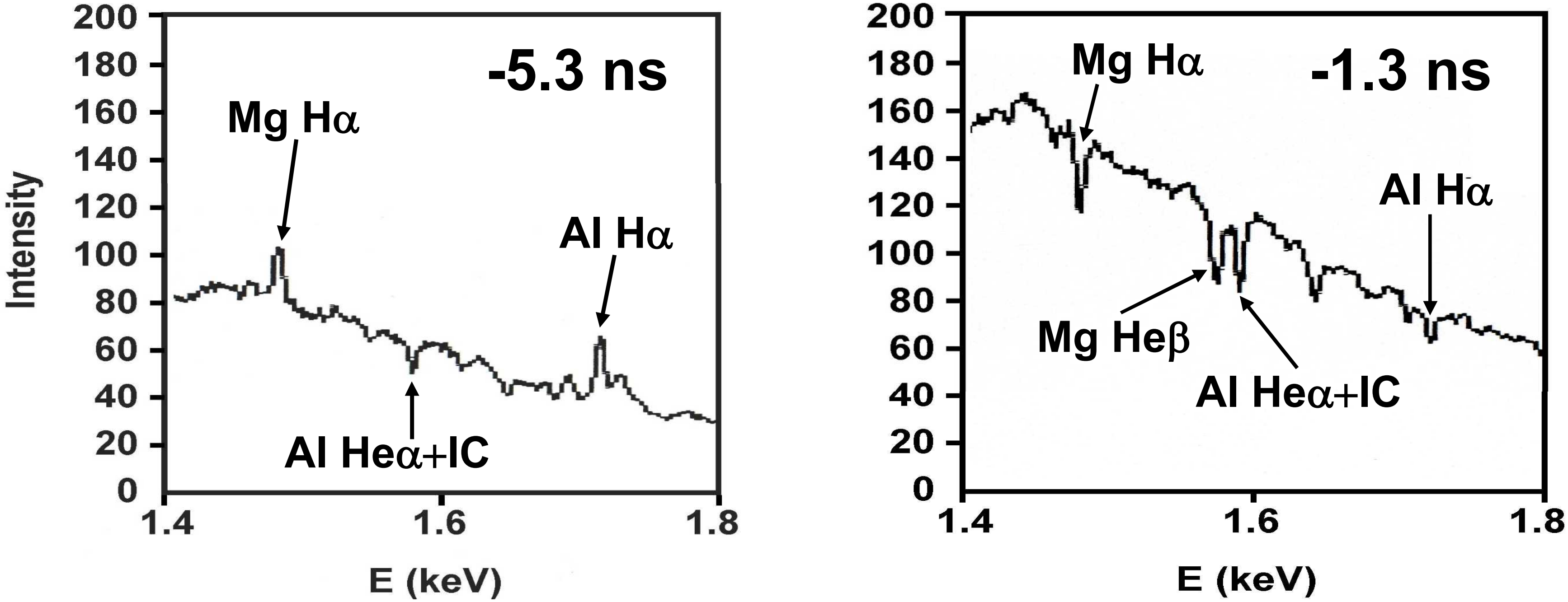
Against this near-Planckian background, the tracer lines are usually seen in absorption.

Why are the Al and Mg lines frequently seen in absorption?

- **The electron density required for local thermodynamic equilibrium (LTE) in the K-shell stages varies as Z^7. For carbon, $N_e = 5 \times 10^{(21\text{-}22)}$ cm^{-3} is needed. This density is attained in dynamic hohlraums.**
- **Al and Mg are far from LTE ($N_e = 10^{(24\text{-}25)}$ cm^{-3} is needed). The levels of excitation of their lines cannot support blackbody emission, but the background carbon continuum is near-Planckian. Thus, tracer absorption lines are seen when the hohlraum is significantly compressed.**
- **Lines from tracers placed at the ends of the hohlraum are always seen in absorption due to the axial temperature gradient. See the Z 1299 spectrum below.**

Shot Z 1025 (top) shows the transition from emission to absorption lines in time-resolved, axial spectra

In this shot, both the Al and Mg tracers were at 2 mm depth



In contrast, shot Z 1299 had the Mg tracer at the end, with the Al layer at 2 mm depth.

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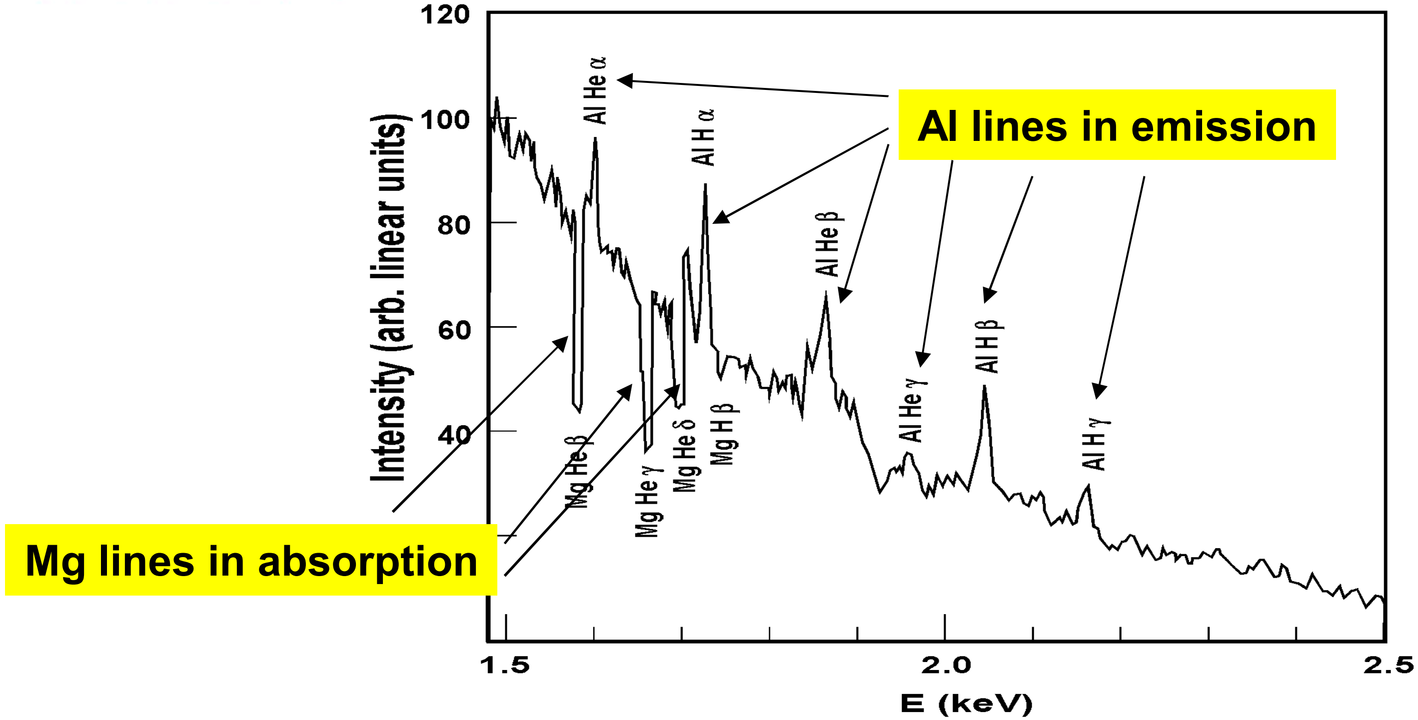

At 5.2 nsec prior to peak power, the outer tracer layer (Mg) produced absorption lines, while the 2 mm deep Al tracer layer was observed in emission. This is a clear indication of an axial temperature gradient.

Detailed multigroup radiation transport is required to capture the absorption line physics of axial Dynamic Hohlraum+tracer radiation.

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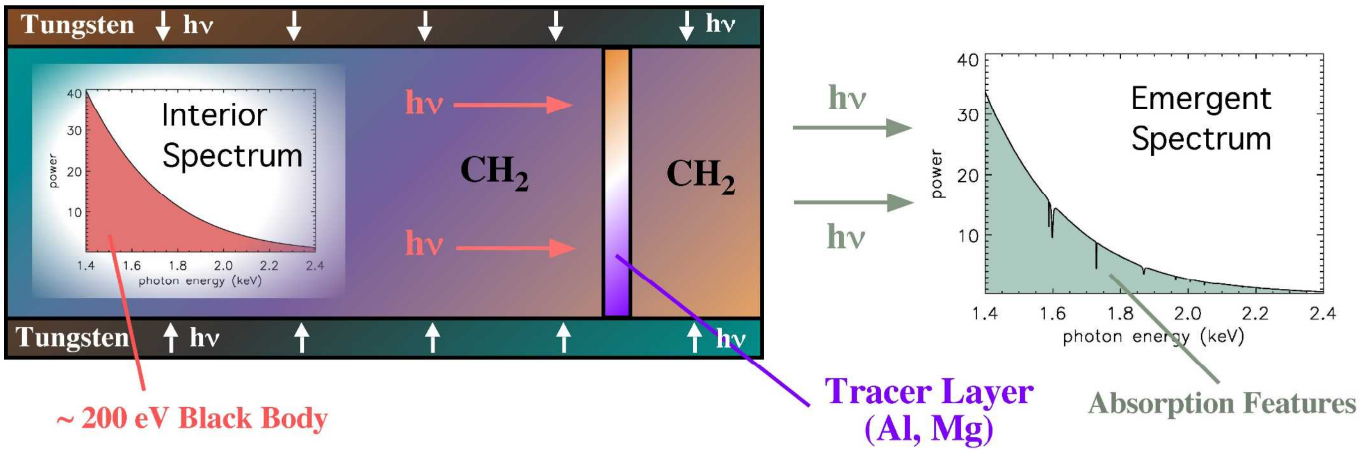
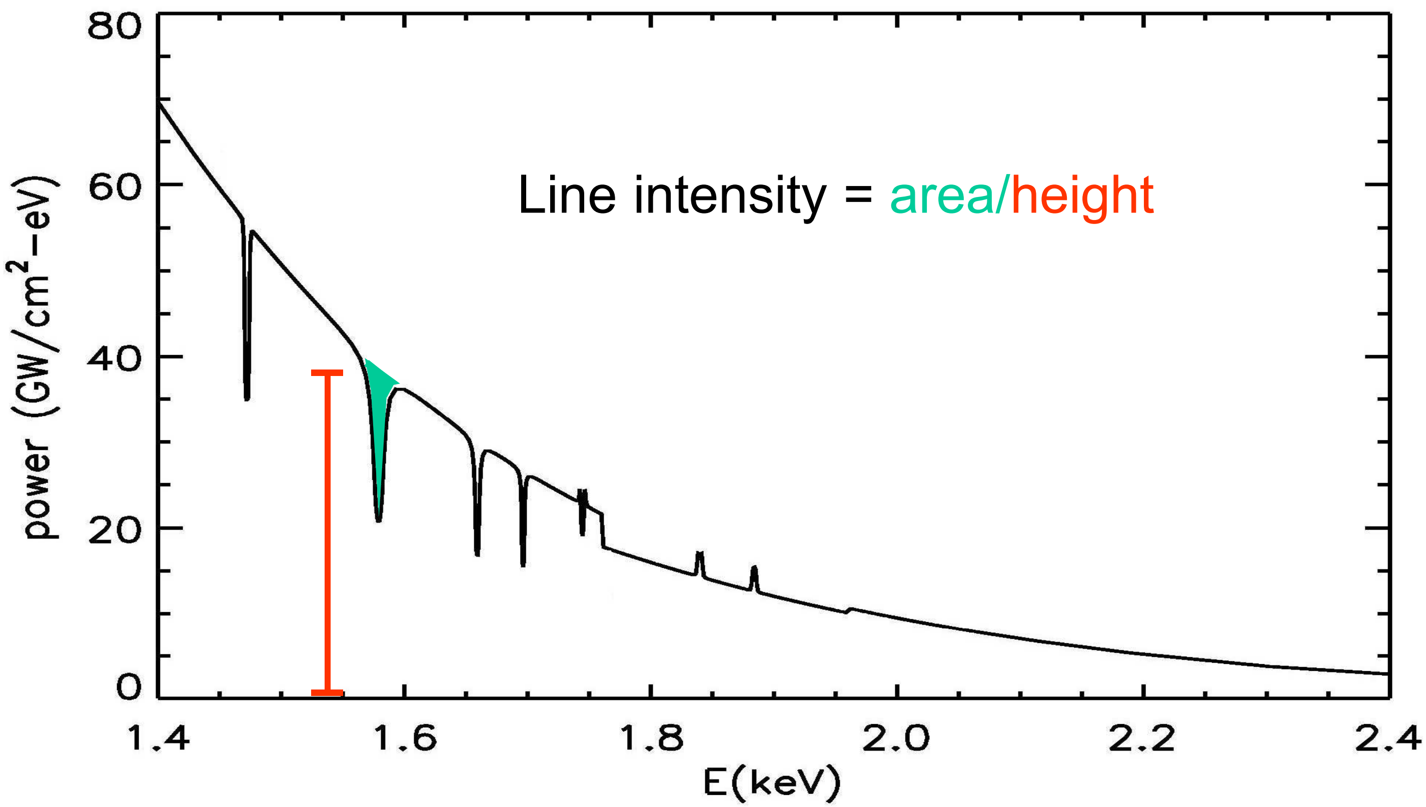


CRE Radiation Model

- Detailed configuration atomic models: C, Mg, Al
- All significant collisional and radiative processes included
- Multigroup radiation transport: 2300 - 4000 total frequency groups, 30 - 60 per line.
- Spectral range covers 10 eV - 5 keV

To do quantitative fits, we define the line intensity as the area within the profile normalized to the projected continuum intensity at line center.



The best fit spectrum minimizes χ^2 by comparing observed line intensities to a table of calculated intensities.

$$\chi^2 = \sum_{i=1}^{N \text{ (lines observed)}} \frac{(I_{calc,i} - I_{obs,i})^2}{\sigma_i^2}$$

(σ_i = experimental uncertainty for line i)

Typically, each table contains calculated intensity spectra for 20 densities, 6 core temperatures, 9 outer temperatures, and 7 power laws for the gradient connecting the inner and outer temperatures, i.e., 7560 entries.

Example: for Z 1023, the tracer-inferred radiation temperature agrees moderately well with, and lies between, values obtained with other methods

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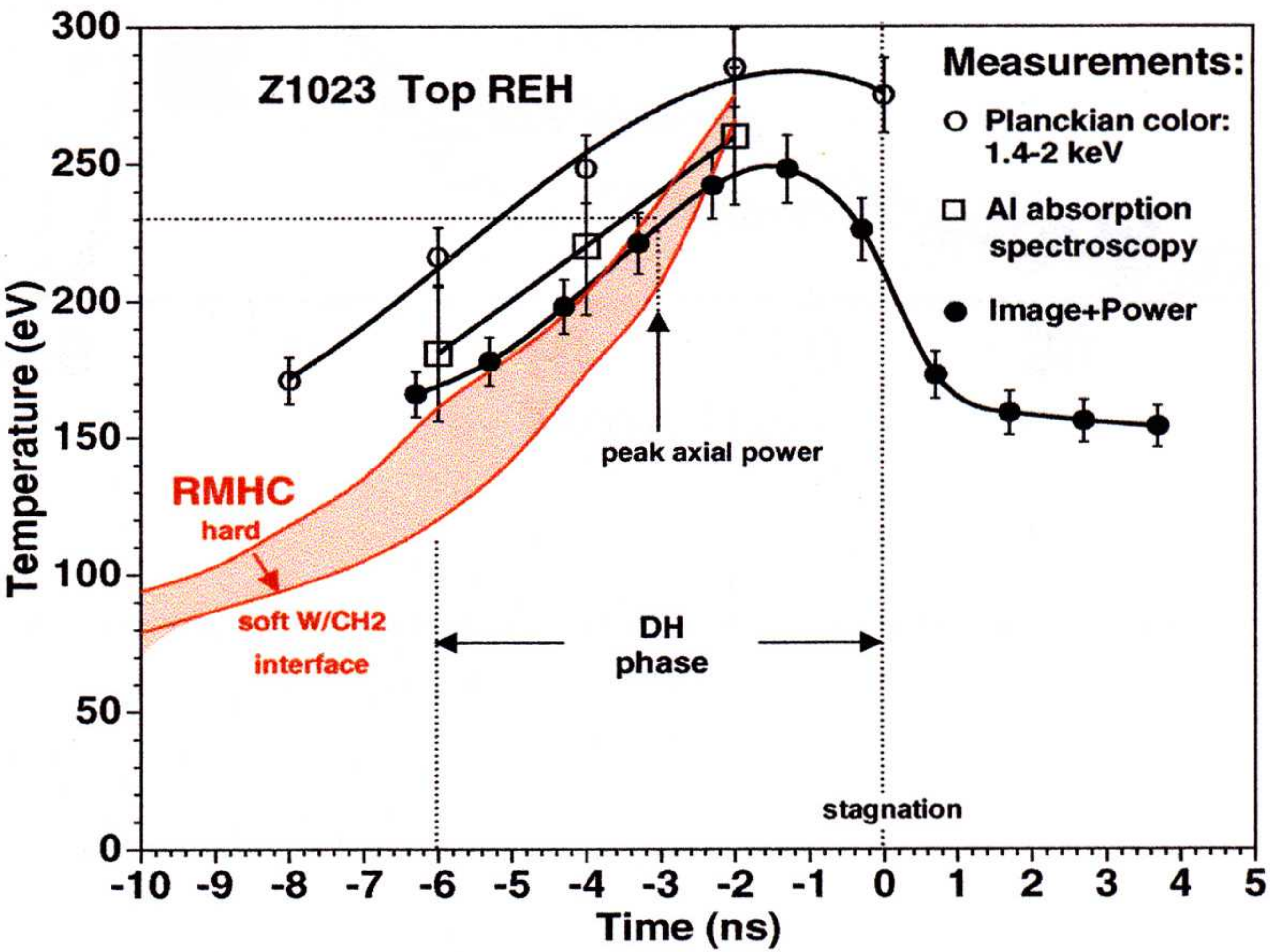

The electron temperatures inferred from the interior and end tracers are in reasonable agreement with 2-D RMHD calculations.

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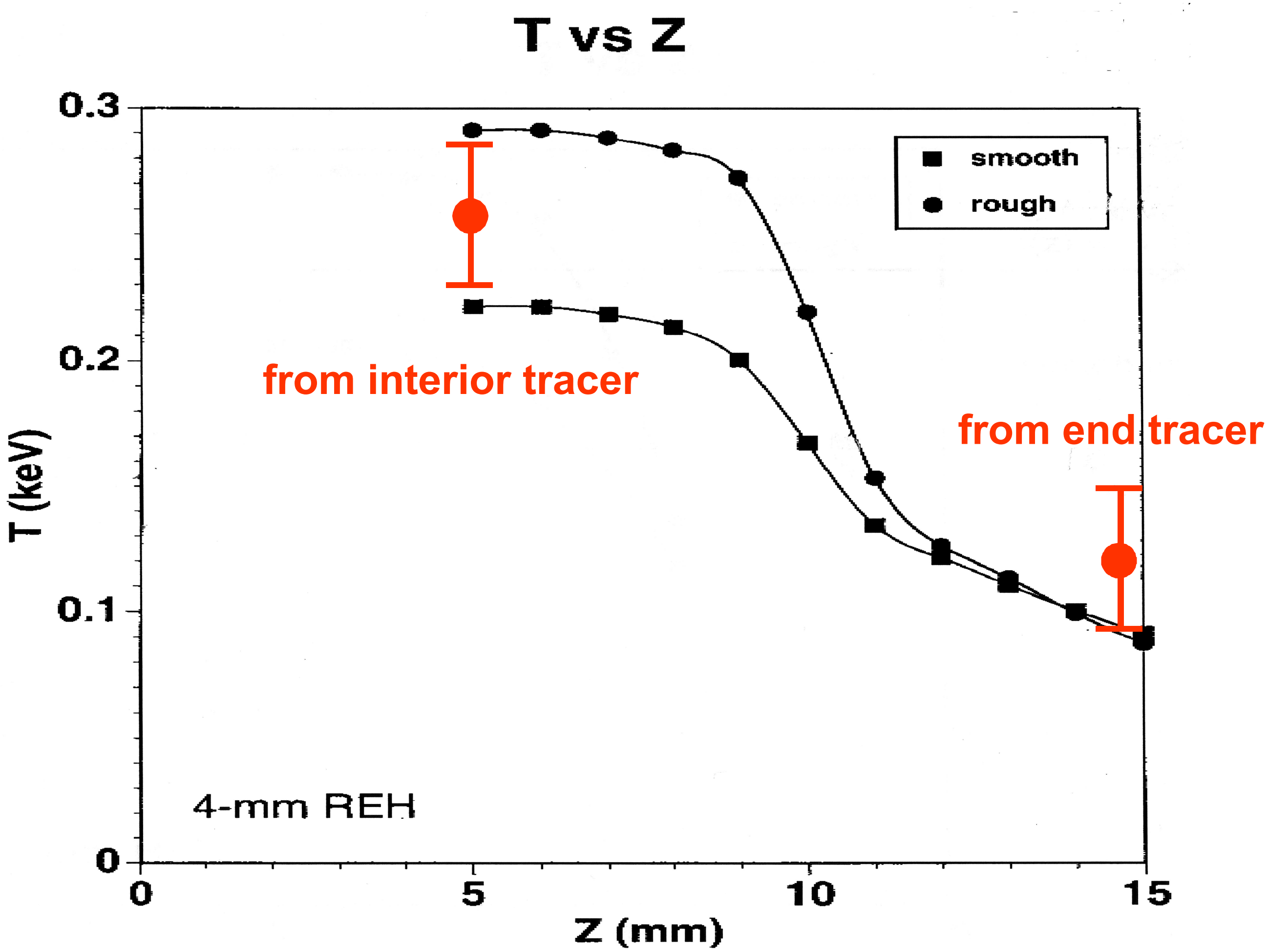
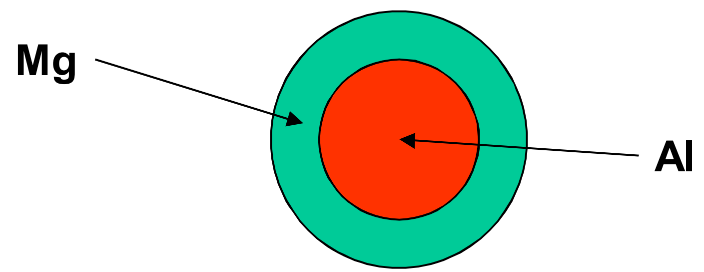


Hohlraum properties: the following conclusions are based on analyses of time resolved and time-integrated spectra from 12 Dynamic Hohlraum shots on Z.

- The top-to-bottom ratio of the radiation temperatures derived from the tracer spectra is 1.01 ± 0.04. *This conclusion from tracer spectroscopy applies, for example, to Z1023, even though the top peak power exceeds the bottom peak power by a factor of > 2.*
- Therefore, the tracer analysis provides no evidence of intrinsic differences between the plasmas at the top and bottom of the Dynamic Hohlraums. This is consistent with spectroscopic evidence that tungsten sliding across the bottom is responsible for the reduced power.
- The tracer analysis shows that, near peak power, the carbon ion density in the interior hohlraum is $4.0 \pm 0.9 \times 10^{21}$ cm^{-3}. In the blowoff plasma the corresponding density is $0.95 \pm 0.11 \times 10^{21}$ cm^{-3}.
- There is excellent agreement between the radiation temperatures inferred from the interior and end tracers: 200 ± 26 eV vs. 211 ± 28 eV, respectively. The electron temperature in the blowoff region is cooler.

A future experimental enhancement:

“Donut” tracers to diagnose radial gradients: as in this end-on view of the cylindrical target.



Different conditions inferred by separately analyzing the Mg and Al lines will provide our first look at the radial variation of temperature and density.

Summary

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- Tracer layer absorption line spectroscopy is a useful and robust diagnostic for Dynamic Hohlraums.
- The basic radiation physics of the tracer line formation is understood and is captured by our model.
- Properties of Dynamic Hohlraums driven by Z have been derived from 12 shots. There is no evidence of intrinsic differences between plasma conditions near the top and bottom. T_{rad} is $\geq$ 200 eV.
- The interior hohlraum plasma is 4-5 times as dense as the blowoff. The blowoff electron temperature of ~ 120 eV is about half that of the hohlraum interior.