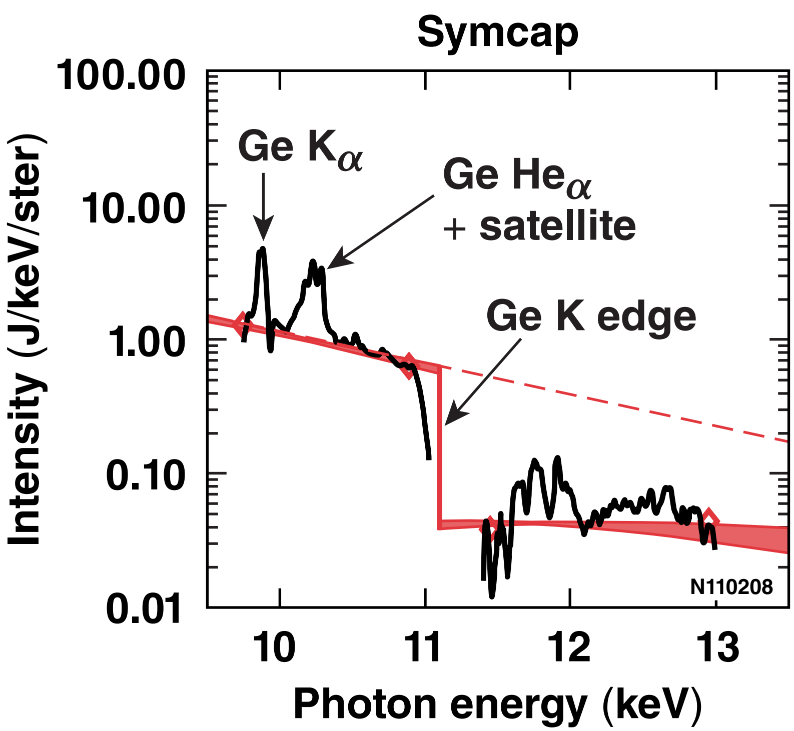
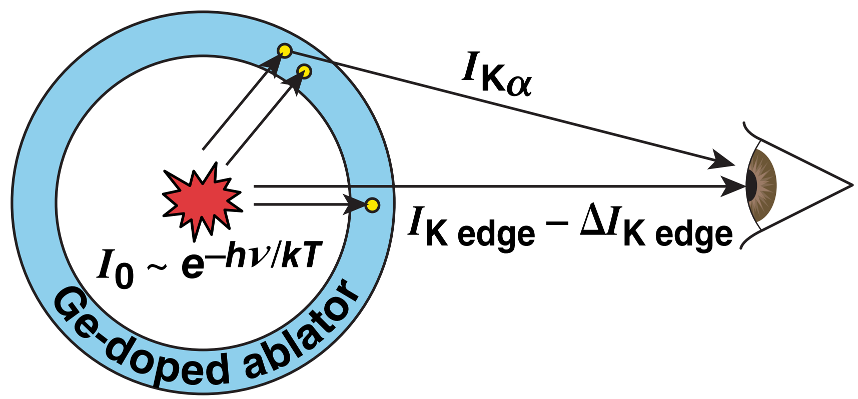
Analysis of Diagnostic X-Ray Spectra of Implosions at the National Ignition Facility





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Summary

Spectroscopy of the Ge dopant in NIF implosion capsule shells provides a useful core, shell, and mix diagnostic

- The intensity of Ge He_α satellite emission gives, with detailed atomic modeling, the mass of shell material mixed into the core
- The measured K_α emission is consistent with a model based on a cold shell source driven by core continuum emission
- K_α emission is directly related to the areal density of the shell Ge near peak compression

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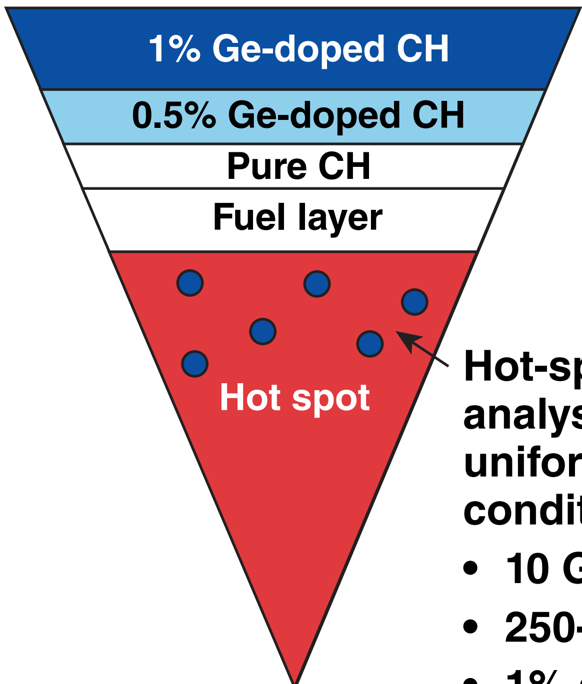
[4] Talk PO6.00009
[5] Talk CO8.00013

Mix mass is modeled as multiple spheres of ablator mass with uniform plasma conditions and areal density

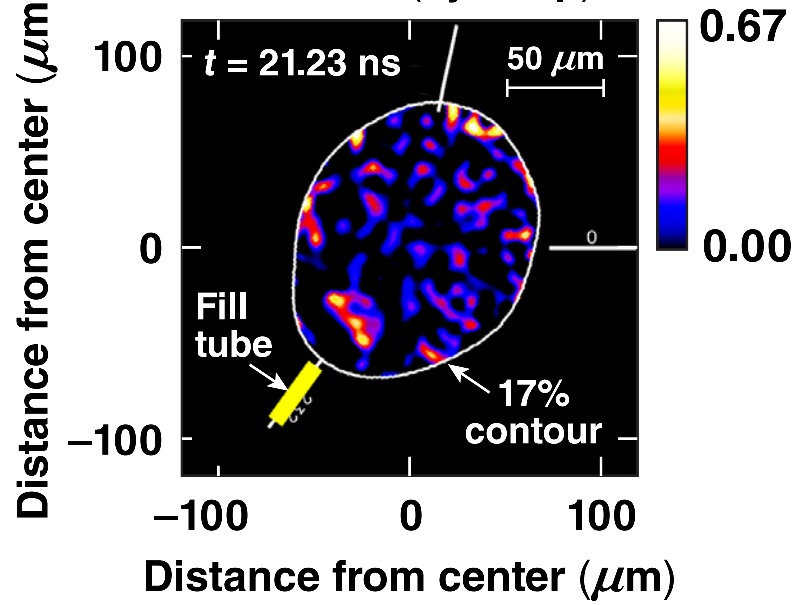
Target near peak compression



Hot-spot mix-mass analysis assumes uniform plasma conditions with:

- 10 Gbar < P < 50 Gbar
- 250-ps emission
- 1% atomic Ge dopant and 30% shell transmission (lower limit)

N110208 (symcap)

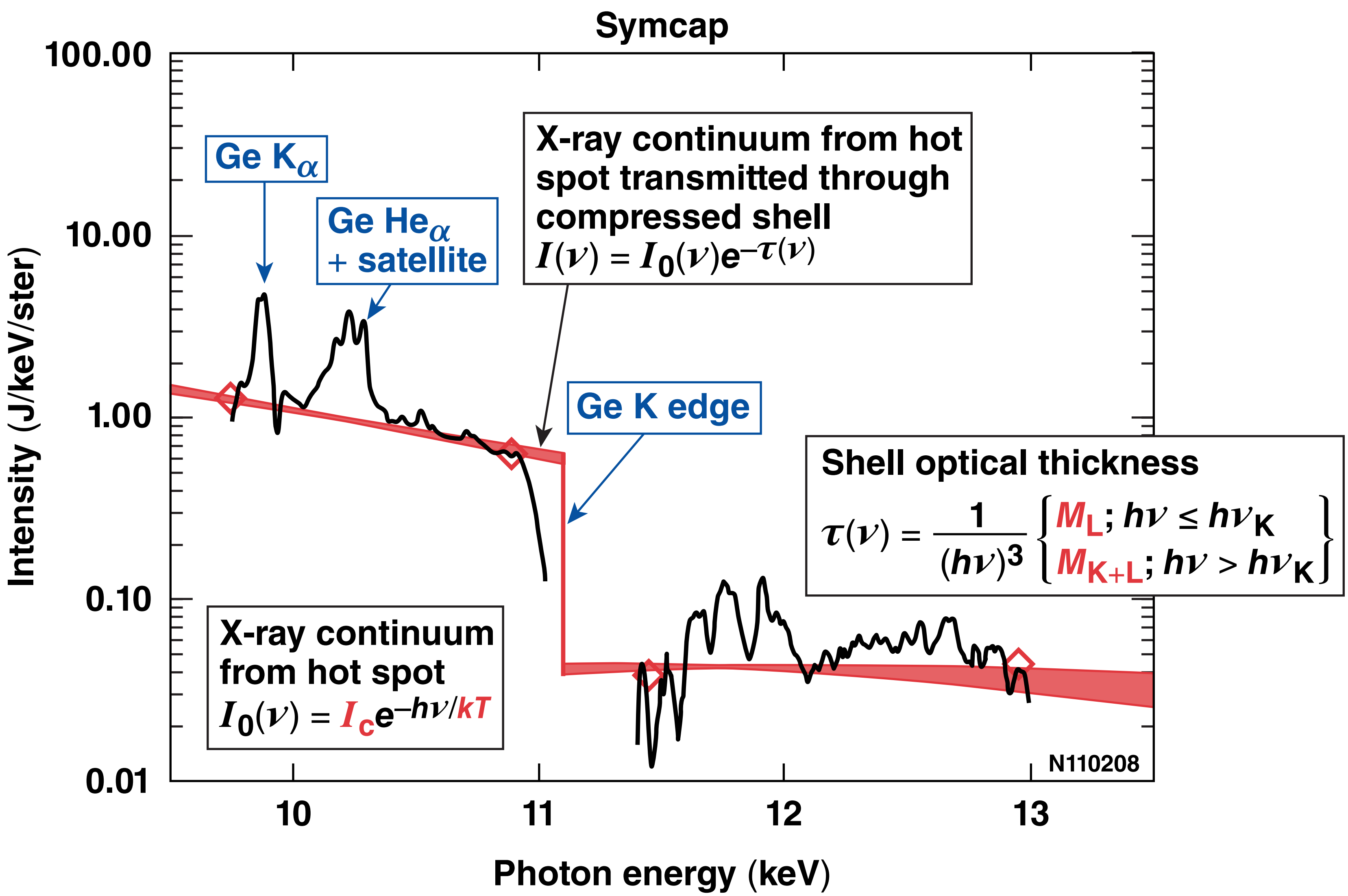


Fourier-analyzed, gated, broadband implosion images taken along hohlraum axis around peak compression*

E19884c

*M. A. Barrios *et al.*, PO6.00006

The absolutely calibrated x-ray spectrum is modeled with attention to three key features



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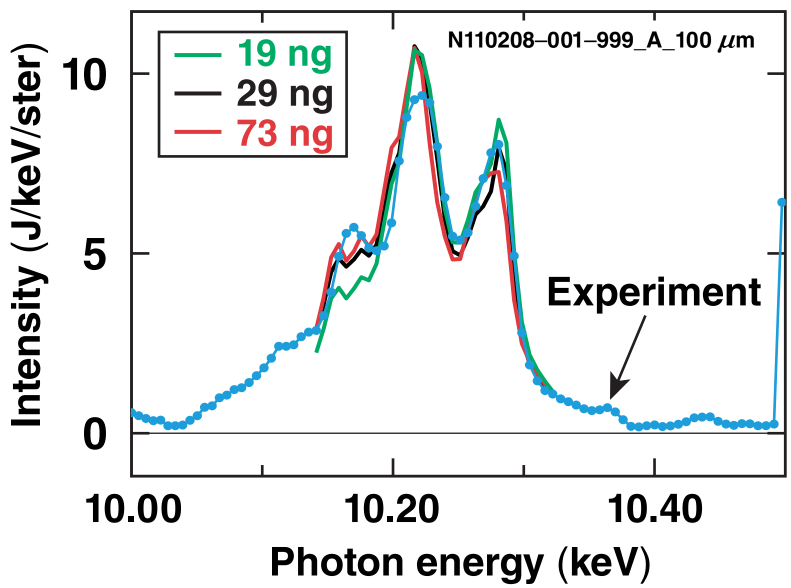
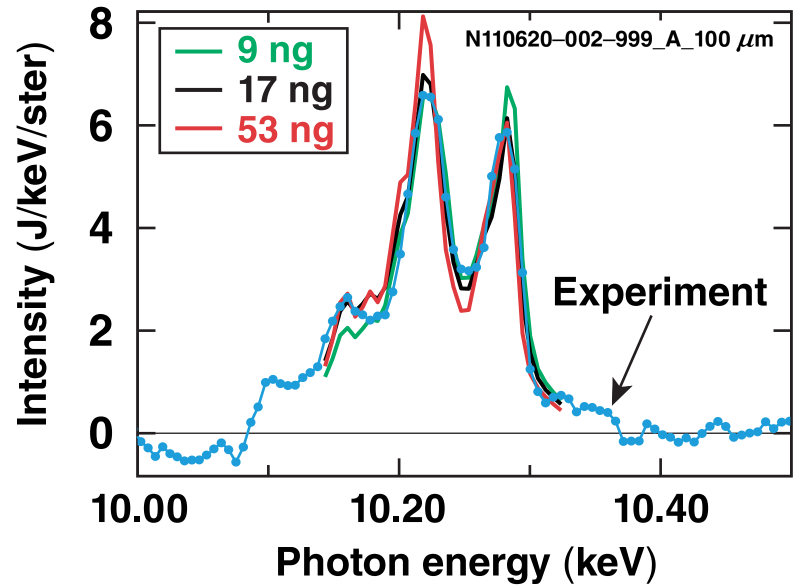
The line shape of the Ge He$_\alpha$ and satellite emission is fit to the model profiles to infer n_e, T_e, and ρR_{Ge}

- The amount of mix mass is determined from inferred plasma conditions and the absolute brightness of the Ge He$_\alpha$ and satellite emission.

Symcap: n_e = 1.0 (+0, –0.5) × 10^{25} cm^{-3}
T_e = 2.3 (+0.4, –0.3) keV
ρR_{Ge} = 0.125 (+0.025, +0.1) mg/cm^2
Mix mass = 29 (–10, +44) ng

DT: n_e = 0.8 (+0.2, –0.5) × 10^{25} cm^{-3}
T_e = 2.4 (+0.6, –0.3) keV
ρR_{Ge} = 0.075 (+0, –0) mg/cm^2
Mix mass = 17 (–8, +36) ng





- Spectrum was corrected for shell attenuation
- Sphere diameter ~ μm
- Number of spheres ~ 10^2 to 10^4

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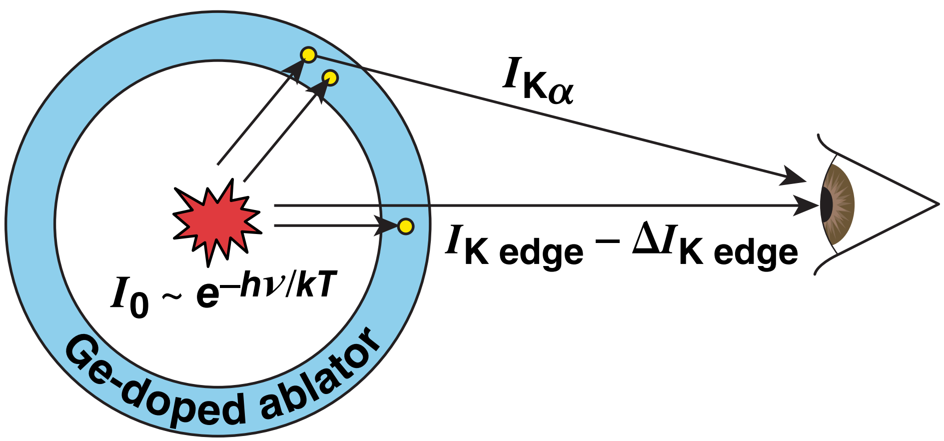
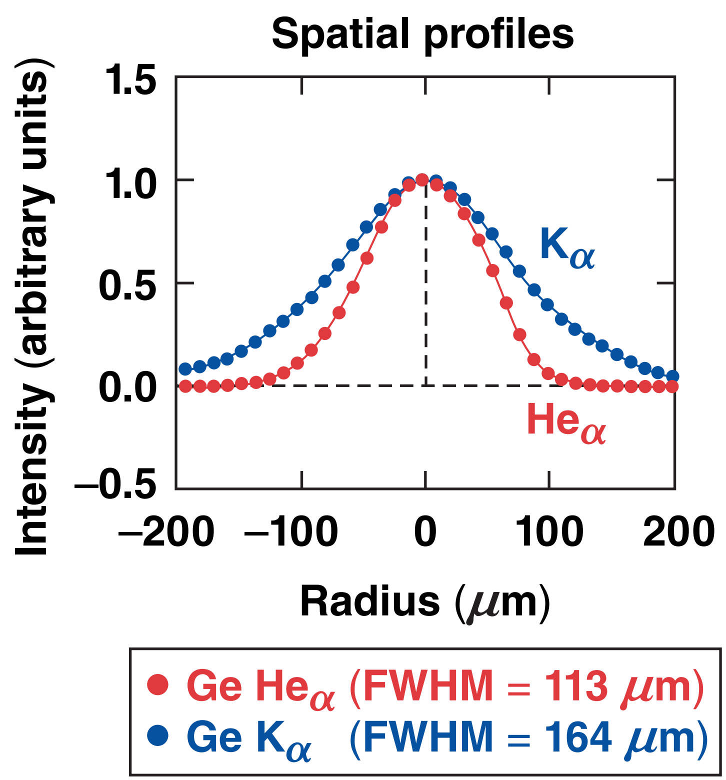
The K_α emission appears in the spectrum in direct proportion to the K-shell absorption in a spherical absorber model



$$\frac{\int I_{K_\alpha} dh\nu}{\Delta I_{K\ edge} kT} = \omega_{K_\alpha} F(\tau_K, \tau_L, kT)$$

$$\mu_K \rho_{Ge} R = \ln\left(\frac{I_{K\ edge}}{I_{K\ edge} - \Delta I_{K\ edge}}\right)$$

Ge fluorescence efficiency $\omega_{K_\alpha} = 0.539$*



HSXRS
100-μm spatial resolution

TC9740

*J. H. Hubbell *et al*., J. Phys. Chem. Ref. Data 23, 339 (1994).

NIC

The ratio of K_α emission to K-edge attenuation is a function of core temperature and shell optical thickness

UR LLE

$$\frac{\int I_{K_\alpha} \mathrm{d}h\nu}{\Delta I_{\mathrm{K\ edge}}\, kT} = \omega_{K_\alpha} F(\tau_K, \tau_L, kT)$$

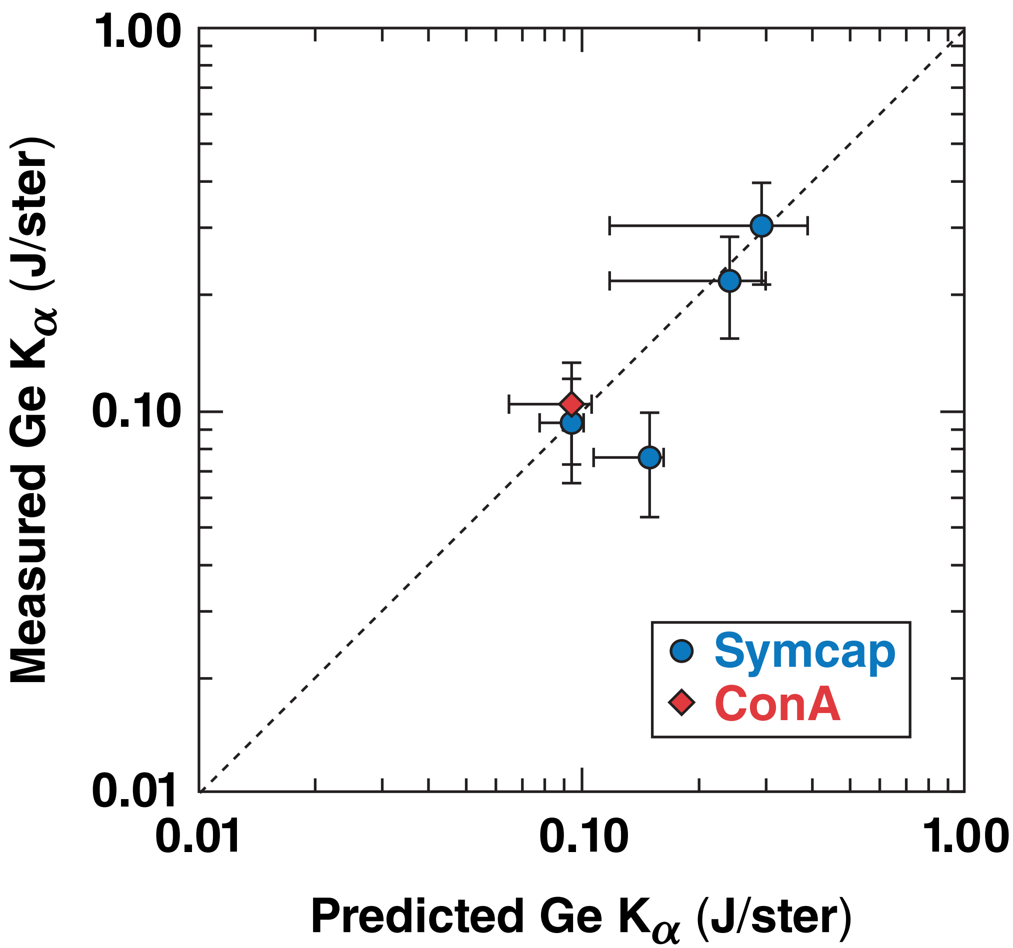
The function *F* takes into account:

$$F(\tau_K, \tau_L, kT) \approx \frac{h\nu_{K_\alpha}/h\nu_K}{\left(1 + kT/h\nu_K\right)} \left\langle 1 - e^{-(\tau_K + \tau_L)(h\nu_K/h\nu)^3} \right\rangle_{kT} \left(\frac{\tau_K}{\tau_K + \tau_L}\right) \times \ldots$$

- Converting a photon number ratio to an energy ratio
- The fraction of potential K-shell photoionizing continuum that is absorbed
- Only K-shell photoionization leads to K_α emission
- Absorption of the measured emission by τ_L
- Radiation-transport geometry in the thin-shell limit

TC9741

The measured K_α emission is consistent with the K-shell absorption of the core continuum



- The K_α emission does indicate the Ge areal density of the shell
- The anticipated wider spectral range of Supersnout II will provide more precise continuum parameters

TC9743

Summary/Conclusions

Spectroscopy of the Ge dopant in NIF implosion capsule shells provides a useful core, shell, and mix diagnostic

- The intensity of Ge He_{α} satellite emission gives, with detailed atomic modeling, the mass of shell material mixed into the core
- The measured K_{α} emission is consistent with a model based on a cold shell source driven by core continuum emission
- K_{α} emission is directly related to the areal density of the shell Ge near peak compression

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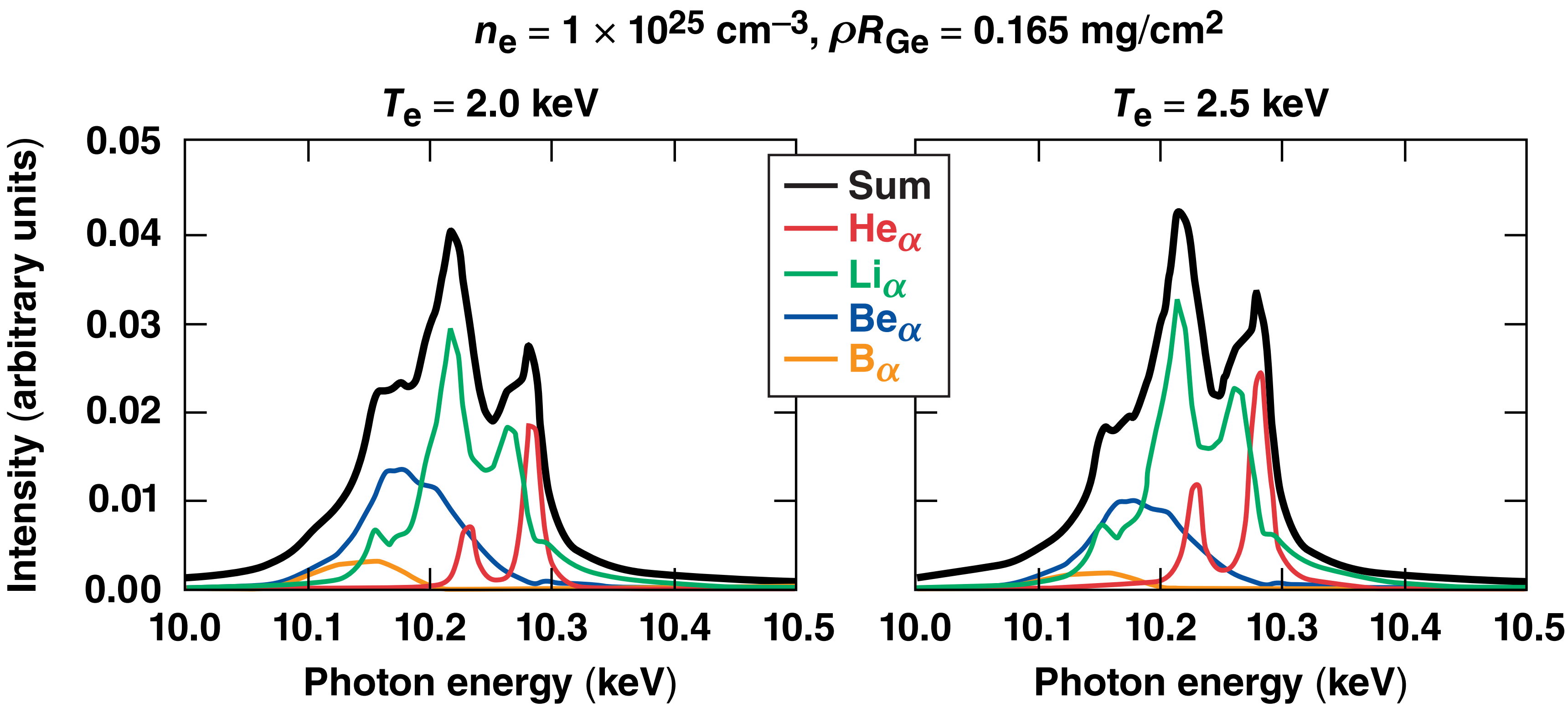
The calculated spectral line shapes are sensitive to variations in the electron temperature



- HSXRS response function has been applied

Spectral feature contains Ge B-like to Ge He-like charge states.

E19885a

Mix mass is estimated from absolute line brightness of the Ge He$_{\alpha}$ line and its satellites

- The total number of Ge ions under steady uniform conditions

$$N_{Ge} = \frac{\iint \langle I_{21}(h\nu) \rangle \, dh\nu \, dt}{\langle p_2(T, \rho, \rho R)\, A_{21}\, E_{21} \rangle \, \Delta t}$$

  and a Ge concentration give the total mix mass M

- The total line intensity per ion $\langle p_2(T, \rho, \rho R)\, A_{21}\, E_{21} \rangle$ is obtained from PrismSPECT* and fit to the spectral data

- Line profiles** and corrections for line-kinetic coupling are modeled in terms of the average photon escape path from a sphere of areal density ρR

- Estimates of ρ and ρR imply a sphere mass: $m = \dfrac{4\pi(\rho R)^3}{3\rho^2}$, and a number of spheres $n = M/m$, indicating how the total mass M may be distributed

* J. J. MacFarlane *et al.*, High Energy Density Phys. 3, 181 (2007).
** R. C. Mancini *et al.*, Comput. Phys. Commun. 63, 314 (1991).

The ratio of K$_\alpha$ emission to K-edge attenuation is a function of core temperature and shell optical thickness

$$\frac{\int I_{\mathrm{K}_\alpha}\, dh\nu}{\Delta I_{\mathrm{K\ edge}}\, kT} = \omega_{\mathrm{K}_\alpha} F(\tau_\mathrm{K}, \tau_\mathrm{L}, kT)$$

$$F(\tau_\mathrm{K}, \tau_\mathrm{L}, kT) \approx \frac{h\nu_{\mathrm{K}_\alpha}/h\nu_\mathrm{K}}{\left(1 + kT/h\nu_\mathrm{K}\right)} \;\frac{\int_{h\nu_\mathrm{K}}^{\infty}\left[1 - e^{-(\tau_\mathrm{K}+\tau_\mathrm{L})(h\nu_\mathrm{K}/h\nu)^3}\right] e^{-h\nu/kT}\,\frac{dh\nu}{h\nu}}{\int_{h\nu_\mathrm{K}}^{\infty} e^{-h\nu/kT}\,\frac{dh\nu}{h\nu}} \times$$

$$\left(\frac{\tau_\mathrm{K}}{\tau_\mathrm{K}+\tau_\mathrm{L}}\right)\left[\left(1 + \frac{R_1}{R_2} + \left(\frac{R_1}{R_2}\right)^2\right)\Big/3 - \tau_\mathrm{L}\left(1 + \frac{R_1}{R_2}\right)^2\Big/4\right] \times \ldots$$

- Converting a photon number ratio to an energy ratio
- The fraction of potential K-shell photoionizing continuum that is absorbed
- Only K-shell photoionization leads to K$_\alpha$ emission
- Absorption of the measured emission by τ_L
- Radiation-transport geometry in the thin-shell limit

TC9741a