Spectroscopic Measurements of Fuel–Pusher Mix in Direct-Drive Implosions on OMEGA

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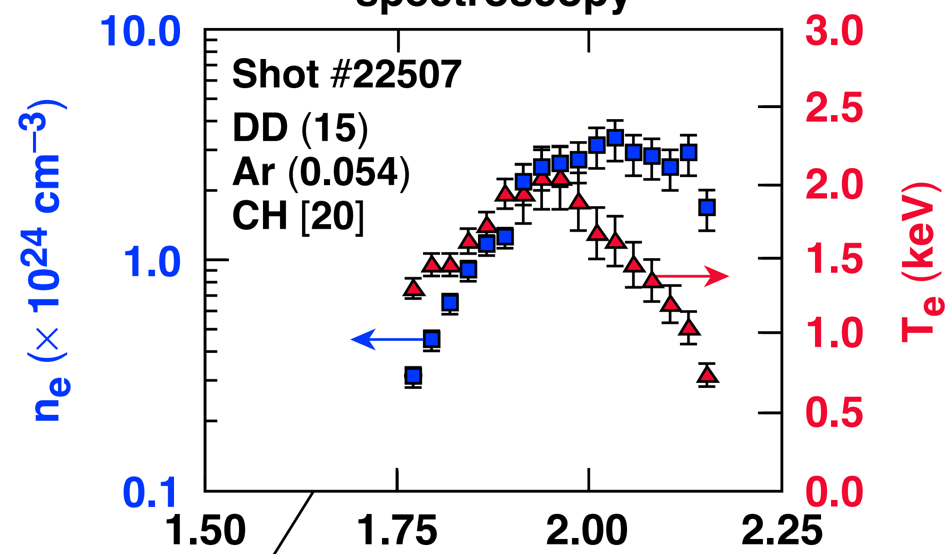
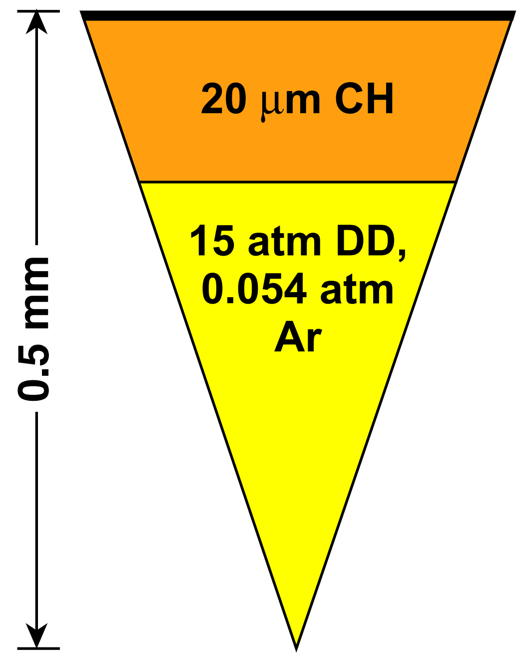
Time-resolved Ar K-shell spectroscopy



$n_e = n_e(D) + n_e(Ar) + n_e(CH)$

ρ_{CH}

$\rho_f R$



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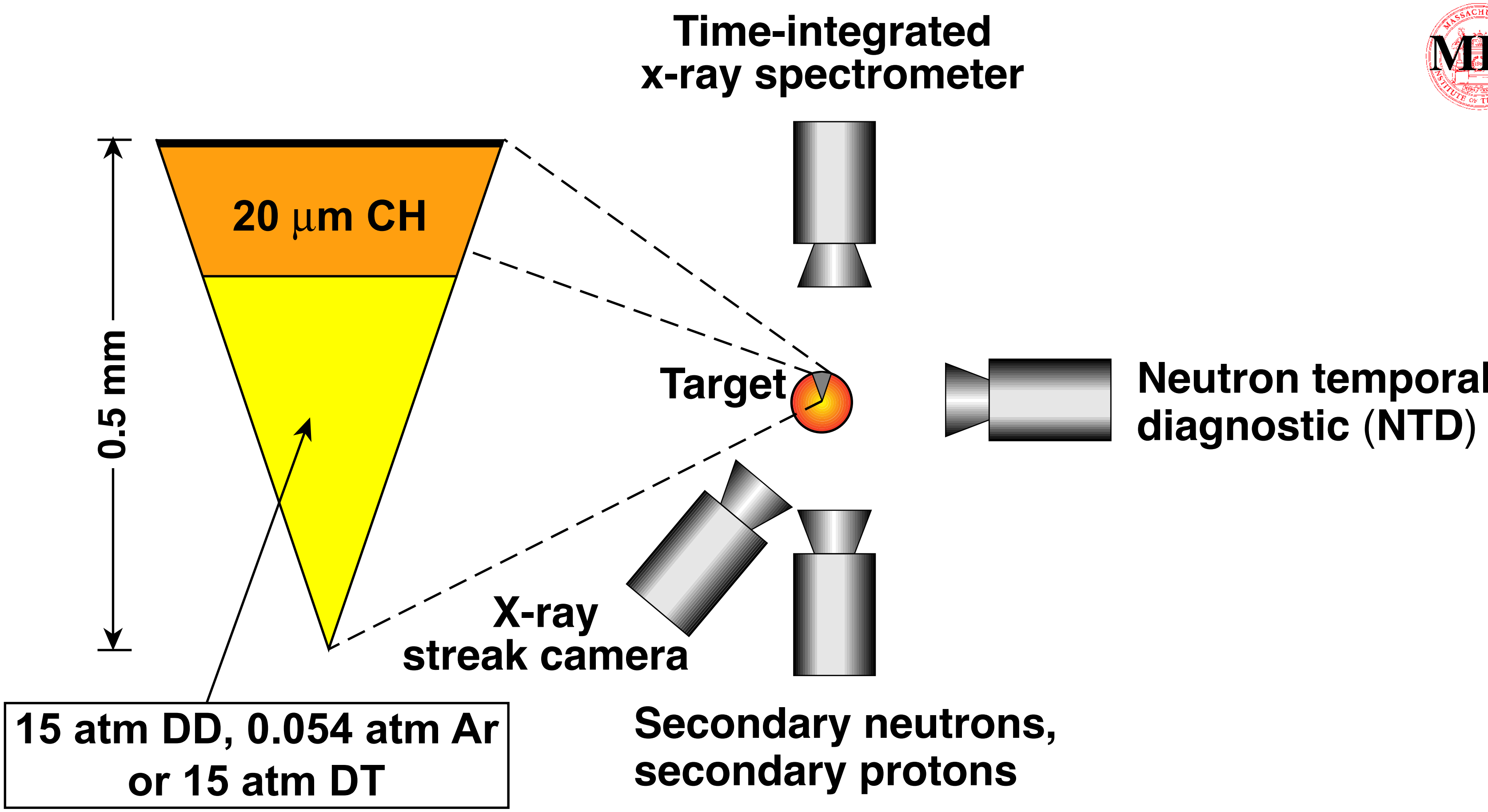
Summary

The estimated core mass composition in the mix region of OMEGA direct-drive implosions with a CR ~ 15 is ~ 1/2 deuterium and ~ 1/2 CH

- Plastic shells with an Ar-doped deuterium fill gas were driven with a 23-kJ, 1-ns square laser pulse with full smoothing.
- The emissivity-averaged core electron temperature and density were inferred from the measured time-dependent Ar K-shell spectral line shapes.
- Ar K-shell emission probes the mantle of fuel surrounding the central hot spot (i.e., the mix region).
- The estimated core deuterium density ρ_f is 3.4($\pm$0.9) g/cm^3, and the estimated core CH density in the mix region is 3.6($\pm$1.2) g/cm^3.

Plastic shells with an Ar-doped deuterium fill gas were driven with a 23-kJ, 1-ns square laser pulse



- Predicted convergence ratio at stagnation ~15
- Laser irradiation with 1-THz SSD, PS, and on-target beam-to-beam power imbalance < 5% rms.

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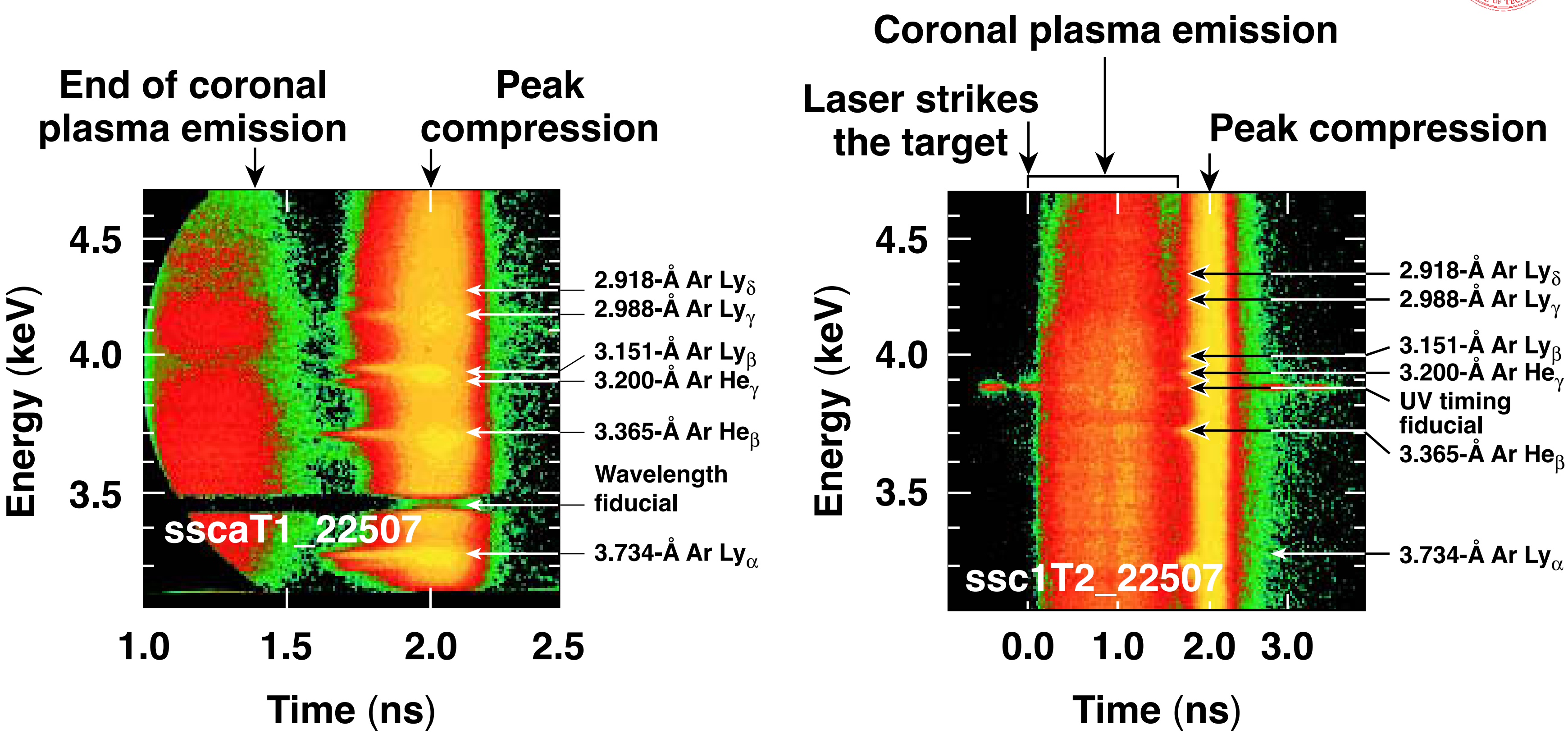
Streaked x-ray spectroscopy is used to measure time-dependent Ar K-shell spectral line shapes



- **Absolute timing of peak x-ray signal is established with a slower streak camera.**

E10931

Time-resolved Ar K-shell spectroscopy provides a direct measure of the core electron density to diagnose core-mix

- Ar K-shell emission from hot, dense plasma ($n_e > 1 \times 10^{23}$ cm^{-3} and $T_e > 1$ keV) has line shapes that depend strongly on density and are insensitive to variations in electron temperature.
- The relative intensities of the Ar K-shell lines and their associated L-shell satellites are sensitive to variations in electron temperature and density.
- Stark-broadened Ar K-shell resonance lines and satellites are calculated with MERL[1,2] assuming uniform core conditions.

[1]R. C. Mancini et al. Comput., Phys. Commun. 63, 314 (1991).
[2]D. A. Haynes et al. Phys Rev., E 53, 1042 (1996).

E10930

Time history of emissivity-averaged core n_e and T_e is inferred from the Ar K-shell spectroscopy

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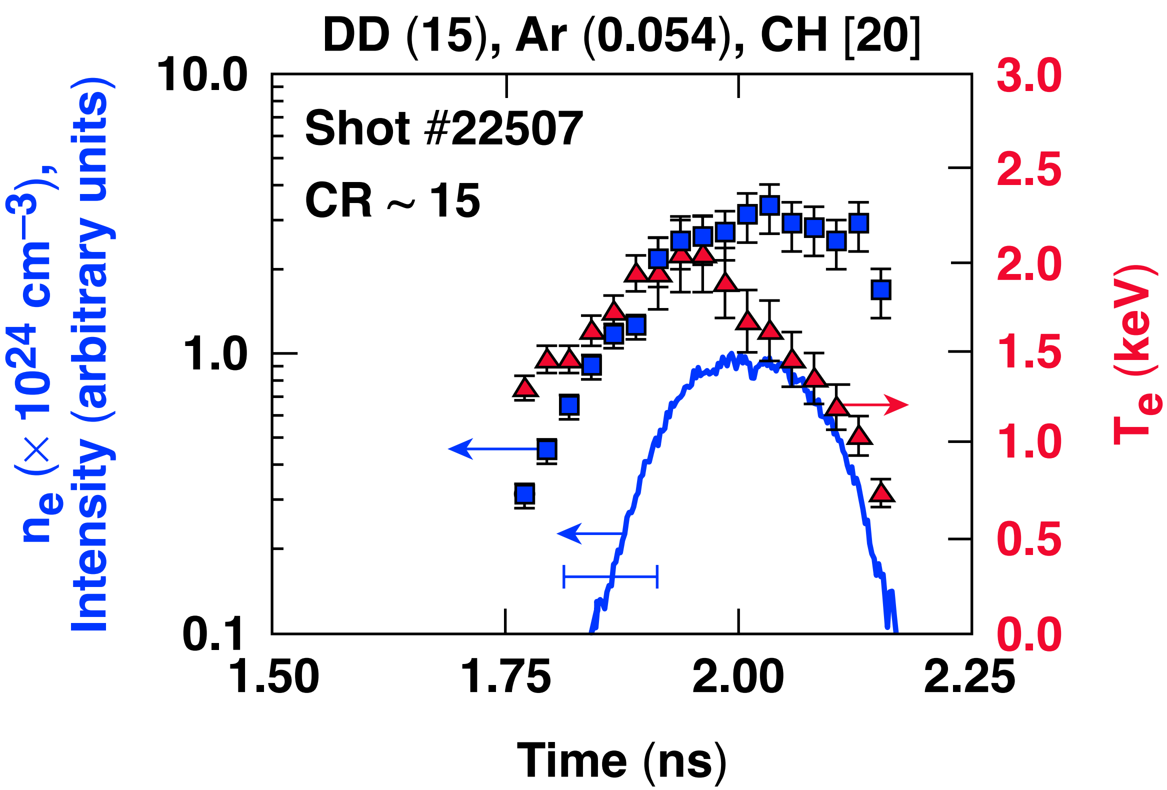
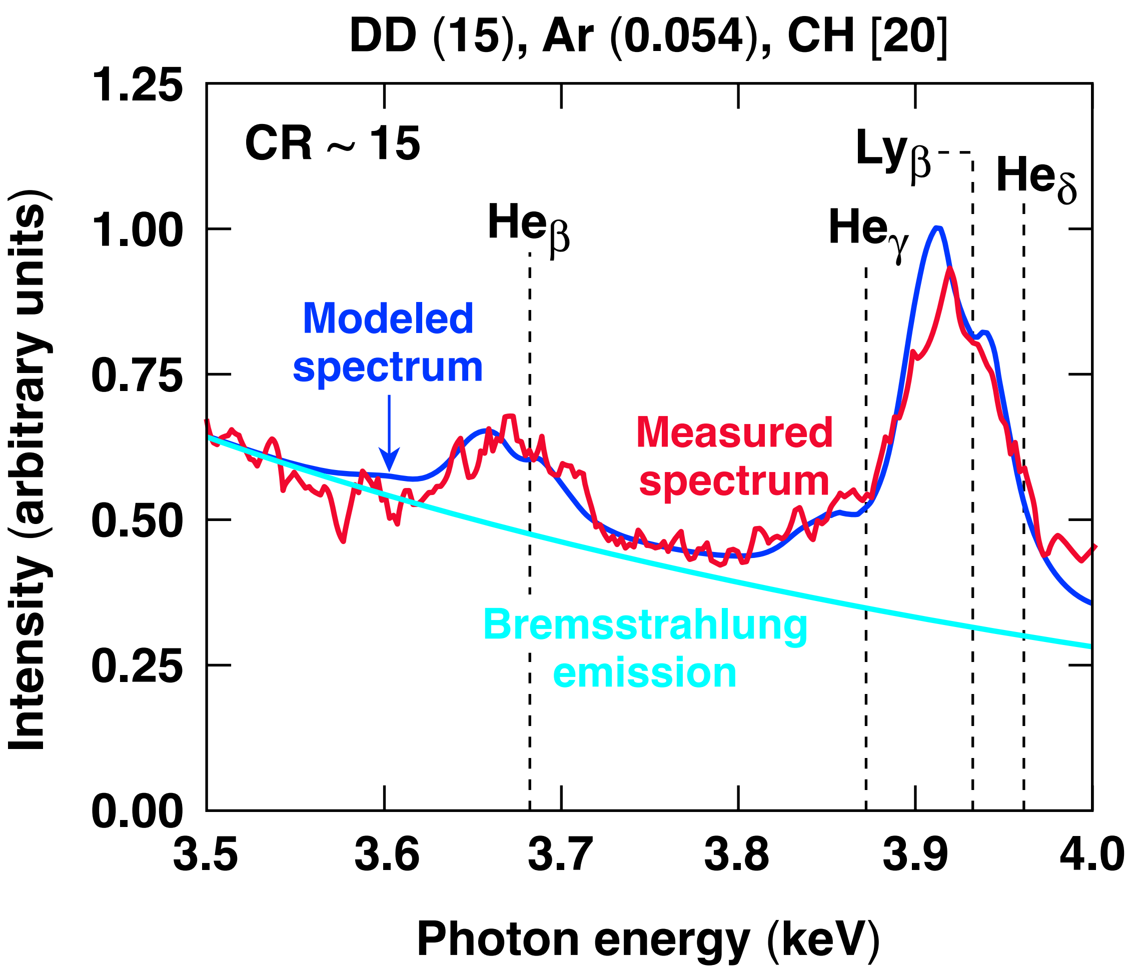


- Significant changes in the Ar K-shell emission spectrum occur during the implosion.
- Peak neutron production is measured ~170 ps±100 ps before peak x-ray production.
- LILAC simulations indicate that peak neutron production occurs at the same time as peak emissivity-averaged T_e.

E10861c

At peak neutron production, $n_e = 2.5 \times 10^{24}$ cm^{-3} and T_e = 2.0 keV



t = 1.93 ns

$n_e = 2.5(\pm 0.5) \times 10^{24}$ cm^{-3}

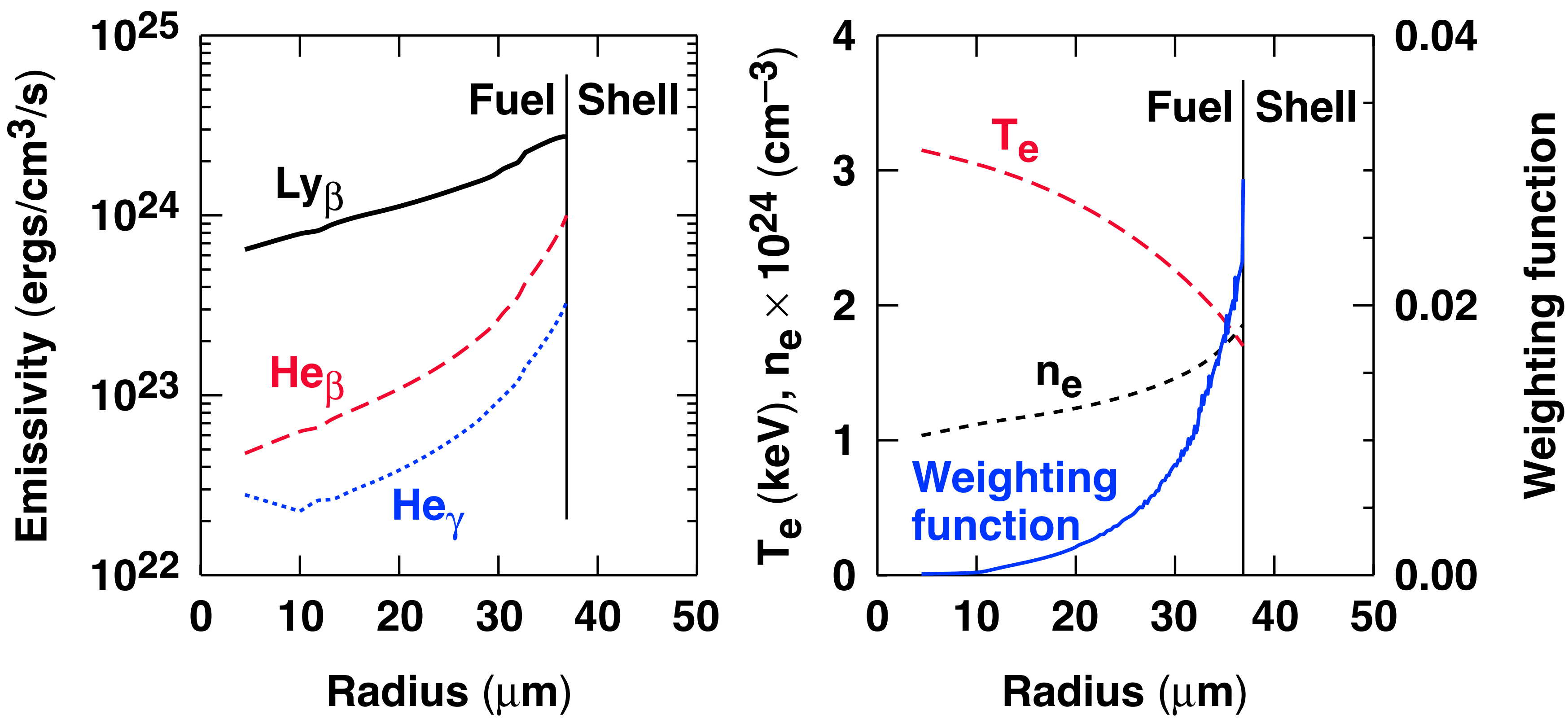
$T_e = 2.0(\pm 0.2)$ keV

- Electron pressure ~ 8 Gbars

E10863a

1-D simulations reveal the Ar K-shell emission probes the mantle of fuel surrounding the central hot spot

LILAC simulations for DD (15), Ar (0.054), CH [20], CR ~ 15 at t = 1.93 ns (peak neutron production).



- **Emissivity average:**

  weighting function $= \varepsilon(\mathbf{r}) \cdot V_{shell}(\mathbf{r}) / \Sigma\varepsilon(\mathbf{r}) \cdot V_{shell}(\mathbf{r})$

E11138

Spectroscopic results are compared with nuclear measurements of $\rho_f R$ to estimate the amount of core-mix

- The $\rho_f R$ measurement is obtained from knock-on deuteron spectra recorded on similar implosions with a DT fill gas.

$$\boxed{\rho_f R \text{ (knock-ons)} = 15 \text{ mg/cm}^2}$$

- The radius of the imploding core at peak neutron production is estimated from $M_f = 4/3\ \pi\ (\rho_f R)\ R^2$.

$$\boxed{R = 44.6\ \mu\text{m}}$$

- $\rho_f = 3.4\ (\pm\ 0.9)\ \text{g/cm}^3$

Time-resolved x-ray spectroscopy

$$\underbrace{n_e}_{\text{Time-resolved x-ray spectroscopy}} = \underbrace{n_e(D)}_{\rho_f R} + n_e(Ar) + \underbrace{\boxed{n_e(CH)}}_{\rho_{CH}}$$

E10984

Ar dopant has a limited effect on target performance

Shot(s)	Target	$Y_n \times 10^{11}$	Y_{2n}/Y_n	$\rho_f R$ (from Y_{2p})	$\rho_f R$ (from Y_{2n})
22507	DD (15), Ar (0.18%), CH (20)	1.0	1.8×10^{-3}	>8.5 mg/cm^2	<18.1 mg/cm^2
Multiple	DD (15), CH (20)	1.3(±0.08)	$2.1(\pm 0.28) \times 10^{-3}$	—	—

- $\rho_f R$ (knock-ons) = 15 mg/cm^2

E11312

Direct-drive implosions with CR ~ 15 have an estimated core mass composition in the mix region of ~1/2 deuterium and ~1/2 CH

DD (15), Ar (0.054), CH [20]

$n_e(CH) = n_e - n_e(D) - n_e(Ar)$

n_e	2.2×10^{24} cm^{-3} (averaged over 170-ps neutron burnwidth)
T_e	1.9 keV (averaged over 170-ps neutron burn width)
$n_e(D)$	1.0×10^{24} cm^{-3}
$n_e(Ar)$	3.1×10^{22} cm^{-3}
$n_e(CH)$	1.2×10^{24} cm^{-3}
ρ_{CH}	3.6 (±1.2) g/cm^3
ρ_f	3.4 (±0.9) g/cm^3

- Pressure (electron + ion) ~ 11 Gbars
- $n\tau T \sim 7 \times 10^{20}$ m^{-3}s keV

E10932

Summary/Conclusions

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