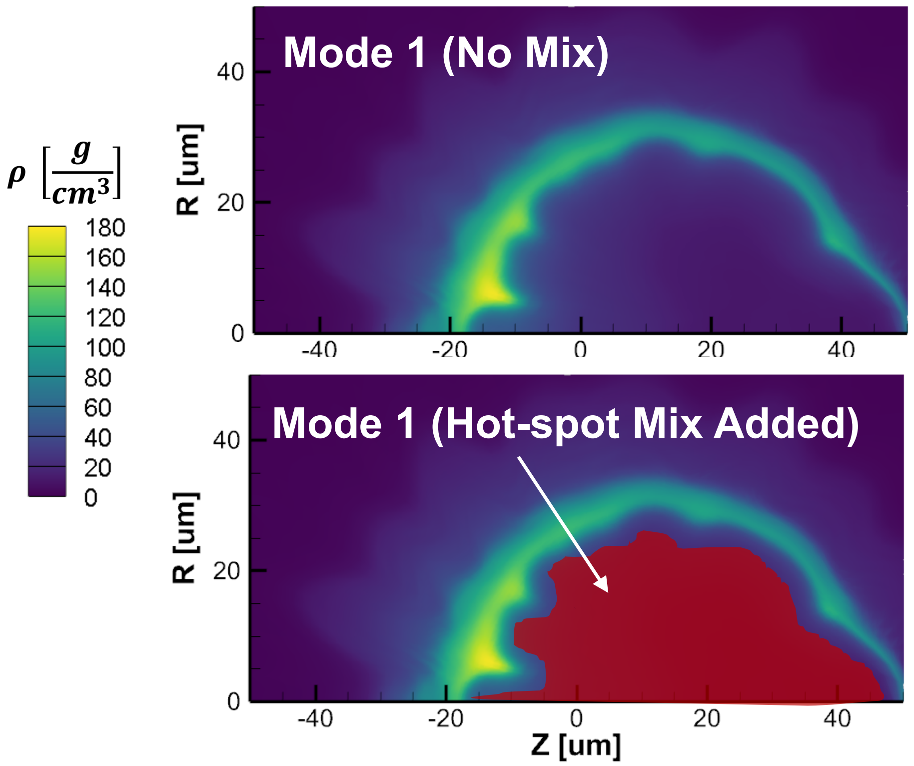
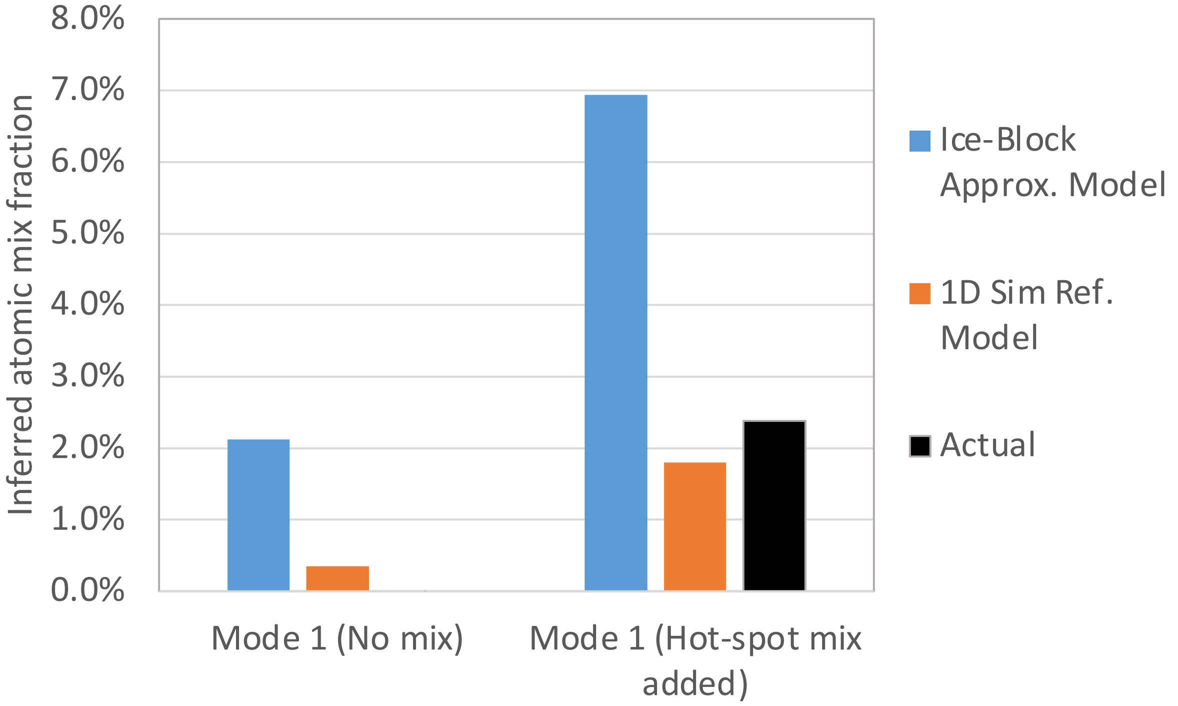
Analysis of Techniques to Infer Hot-Spot Mix using Absolute X-ray Emission for OMEGA Direct-Drive Layered Implosions

OMEGA Cryo Implosion Scenarios



Inferred vs. Actual Mix



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Summary

Accurate hot-spot mix estimates are obtained when using a yield ratio reference Y_ν/Y_n from 1D simulations

- We analyzed two methods that infer hot-spot mix using a no-mix estimate of Y_ν/Y_n (X-ray/Neutron yield)
  1. Ice-block approximation model[1]
  2. 1D sim. reference approximation model

- In tests where $T_e \neq T_i$, the ice-block approximation model was found to overestimate mix

- In contrast, inferring mix using a Y_ν/Y_n reference from 1D simulations not only takes non-equilibrium into account, but also applied well to non-1D scenarios

[1]T. Ma et al., PRL 111, 085004 (2013)

Collaborators

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Our goal is to infer mix in a variety of implosions on OMEGA

- X-ray emission yield Y_ν has a strong Z dependence for fully-ionized plasmas[1]:

$$\varepsilon_\nu \propto n_i^2 \left(\frac{\chi_H}{kT_e}\right)^{\frac{1}{2}} \langle Z\rangle \left[\langle Z^2 g_{FF}\rangle + 2\left(\frac{\chi_H}{kT_e}\right)\left\langle Z^4 e^{\frac{(\chi-\Delta\chi)}{kT}} g_{BF}\right\rangle\right] e^{-\frac{h\nu}{kT}} ; \qquad Y_\nu = \iint \varepsilon_\nu dV dt$$

- Mix is inferred by seeing how much higher $Y_{\nu,exp}$ is above $Y_{\nu\,(Z=1)}$ and back-calculating the resulting $\langle Z\rangle$
  - Requires having an estimate for $Y_{\nu\,(Z=1)}$

- We analyzed two methods for approximating $Y_{\nu\,(Z=1)}$ to infer mix
  1. Ice-block approximation model[2]
  2. 1D simulation-reference model

[1] R. Epstein et al., Physics of Plasmas (1994-present) 22, 022707 (2015)
[2] T. Ma et al., PRL 111, 085004 (2013)

The ice-block approximation model[1] compares a measured yield ratio Y_ν/Y_n to a no-mix, ice-block expectation to infer mix

- **Advantage: Ice-block model assumes uniform conditions in hot-spot**
- **A yield ratio is used so that density, volume, and emission times can be ignored:**

$$\frac{\left(\frac{Y_\nu}{Y_n}\right)_{exp}}{\left(\frac{Y_\nu}{Y_n}\right)^{*}_{\substack{ice-block \\ (Z=1)}} : \quad \frac{C_0 g_{FF} e^{-\frac{h\nu_0}{k\langle T_e\rangle}}}{f_D f_T \langle\sigma v\rangle_{DT}} \frac{\cancel{n_i^2 V \Delta t}}{\cancel{n_i^2 V \Delta t}}} = \underbrace{\frac{\langle Z\rangle}{g_{H,FF}}\left[\langle Z^2 g_{FF}\rangle + 2\left(\frac{\chi_H}{kT_e}\right)\langle Z^4 g_{BF}\rangle\right]}_{\text{Z dependency is now isolated}}$$

*Yield formulas use measured T_e and T_i

[1]T. Ma et al., PRL 111, 085004 (2013)

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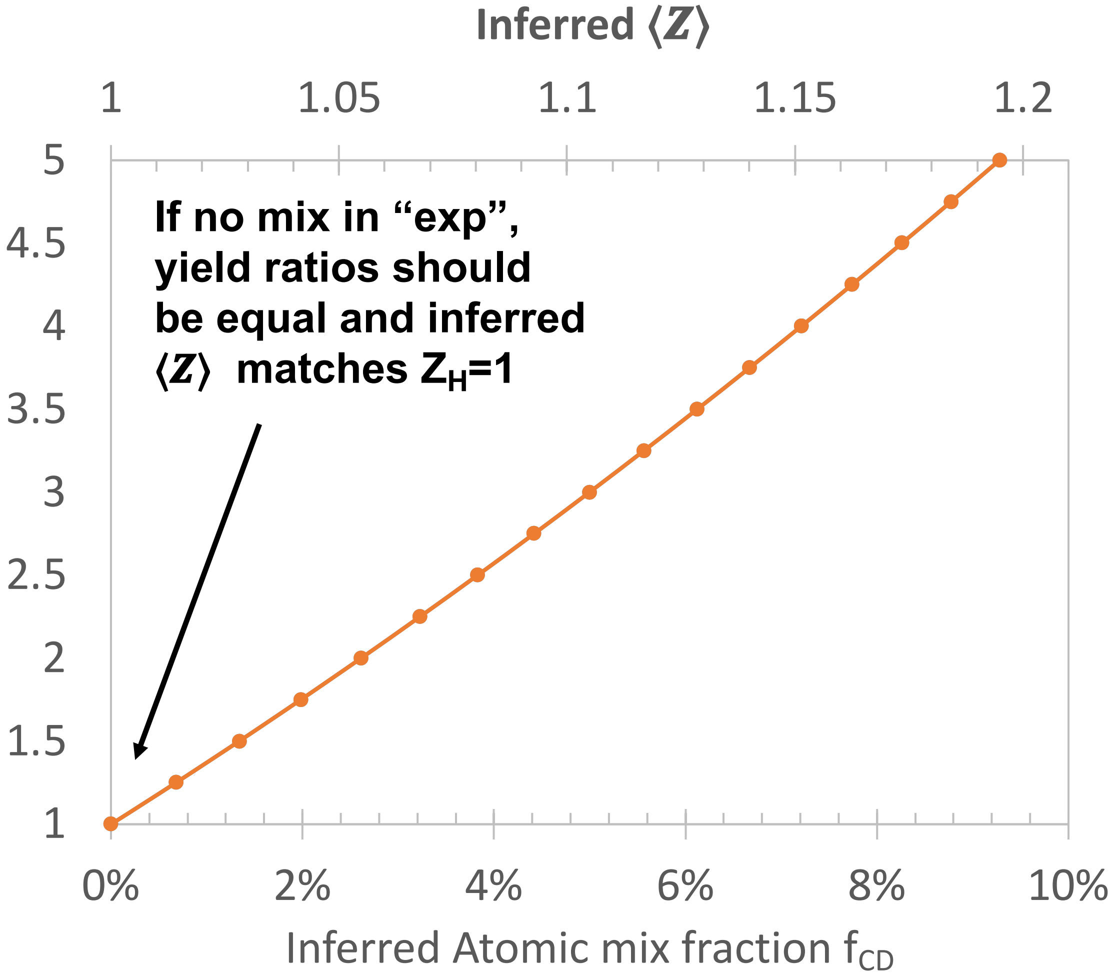
$$\left(\frac{Y_\nu}{Y_n}\right)^{*}_{\substack{ice-block\\(Z=1)}} : \qquad \frac{\left(\frac{Y_\nu}{Y_n}\right)_{exp}}{\dfrac{C_0 g_{FF} e^{-\frac{h\nu_0}{k\langle T_e\rangle}}\,\cancel{n_i^2 V\Delta t}}{f_D f_T \langle\sigma v\rangle_{DT}\,\cancel{n_i^2 V\Delta t}}} =$$



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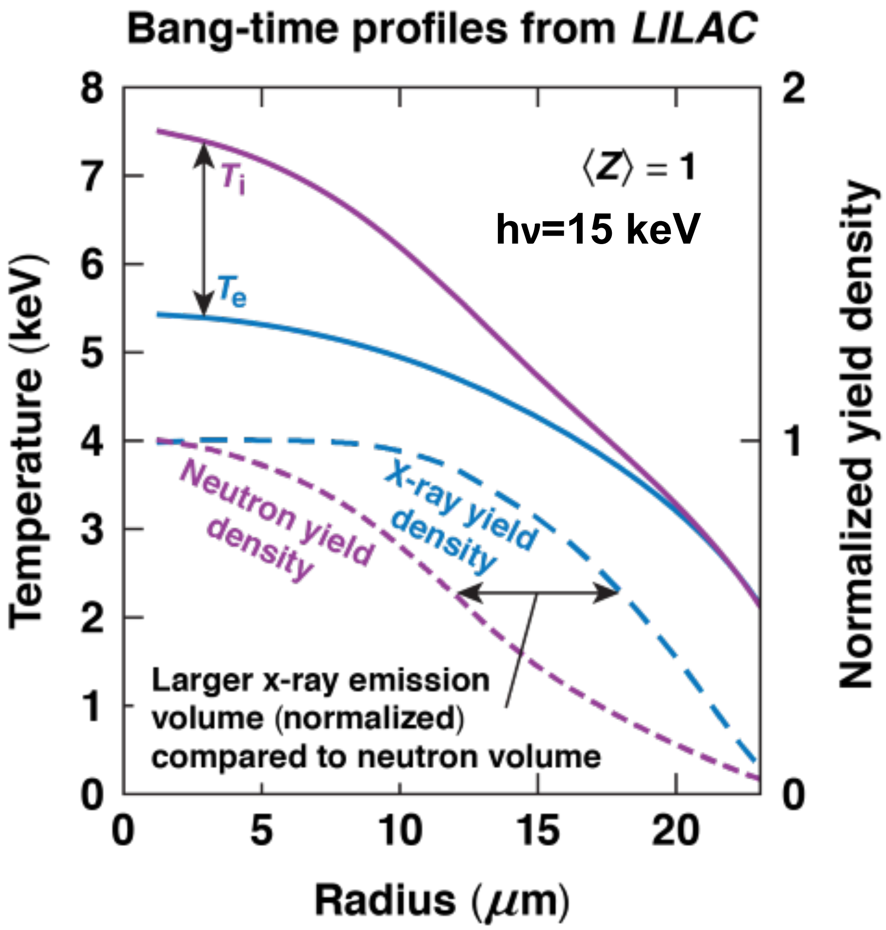
Ice-block mix model breaks down during non-equilibrium conditions (stronger on OMEGA than on NIF)

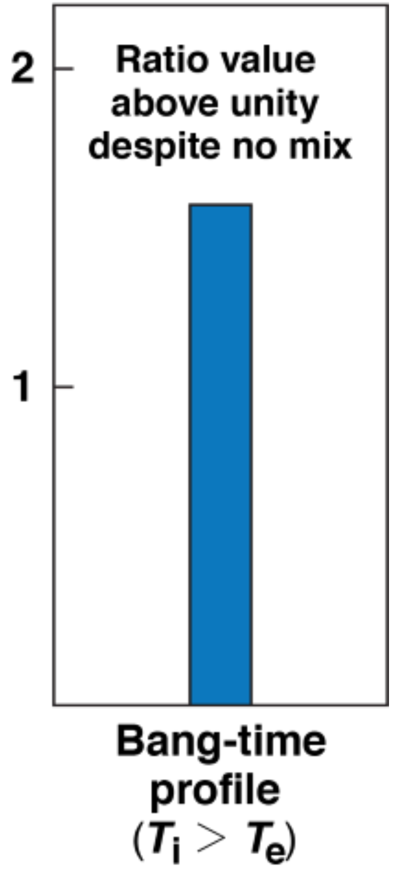
Test case (No Mix):



$$\frac{\left(\frac{Y_\nu}{Y_n}\right)_{Profile}}{\dfrac{C_0 e^{-\frac{h\nu_0}{k\langle T_e\rangle}}}{f_D f_T \langle\sigma v\rangle_{DT}}\;\dfrac{\cancel{n_i^2 V\Delta t}}{\cancel{n_i^2 V\Delta t}}} =$$

Bad assumption.

$V_v > V_n$



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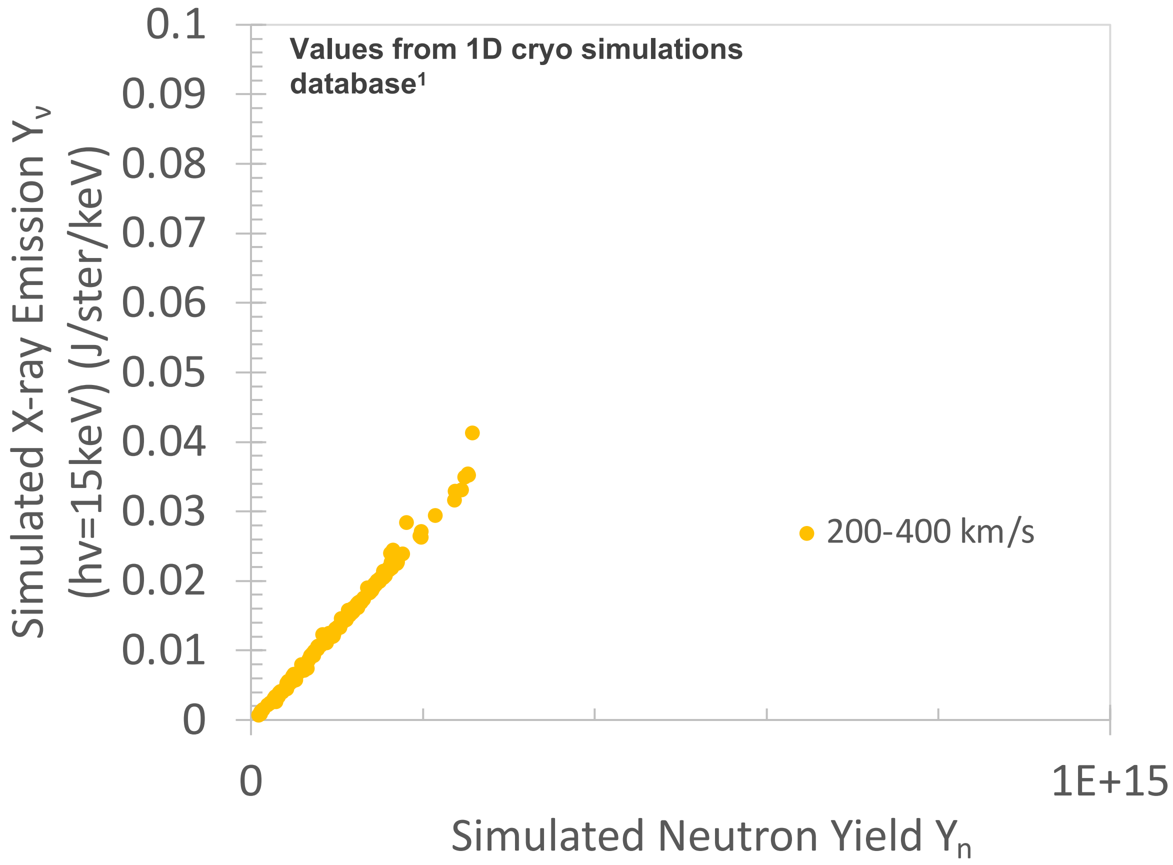
We can bypass the ice-block model limitations by using a simulation approximation for Y_v/Y_n

- A monotonic relation between Y_n and Y_v exists in simulation
  - Higher implosion velocity groups have slightly different Y_v/Y_n ratio
  - *These ratios account for non-equilibrium effects*

- To exploit these relations for inferring mix, we simply assume:

$$\left(\frac{Y_v}{Y_n}\right)_{\substack{exp \\ (No\ Mix)}} = \left(\frac{Y_v}{Y_n}\right)_{1D\ Sim.}$$ of similar v_{imp}



[1]V. Gopalaswamy et al, Nature 565, 581 (2019)

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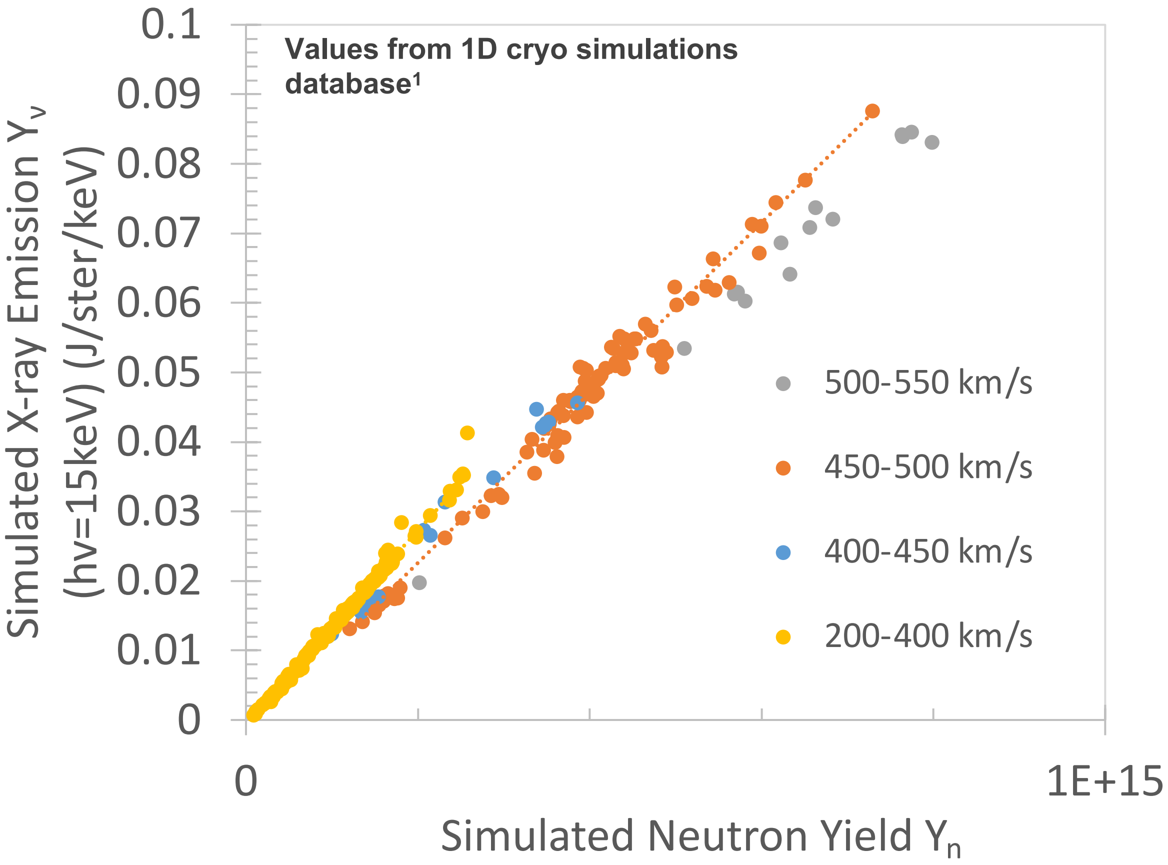


[1]V. Gopalaswamy et al, Nature 565, 581 (2019)

With the no-mix reference for Y_ν/Y_n based on 1D simulations, mix can then be inferred in a similar way to ice-block approximation method

Ice-block approximation model:

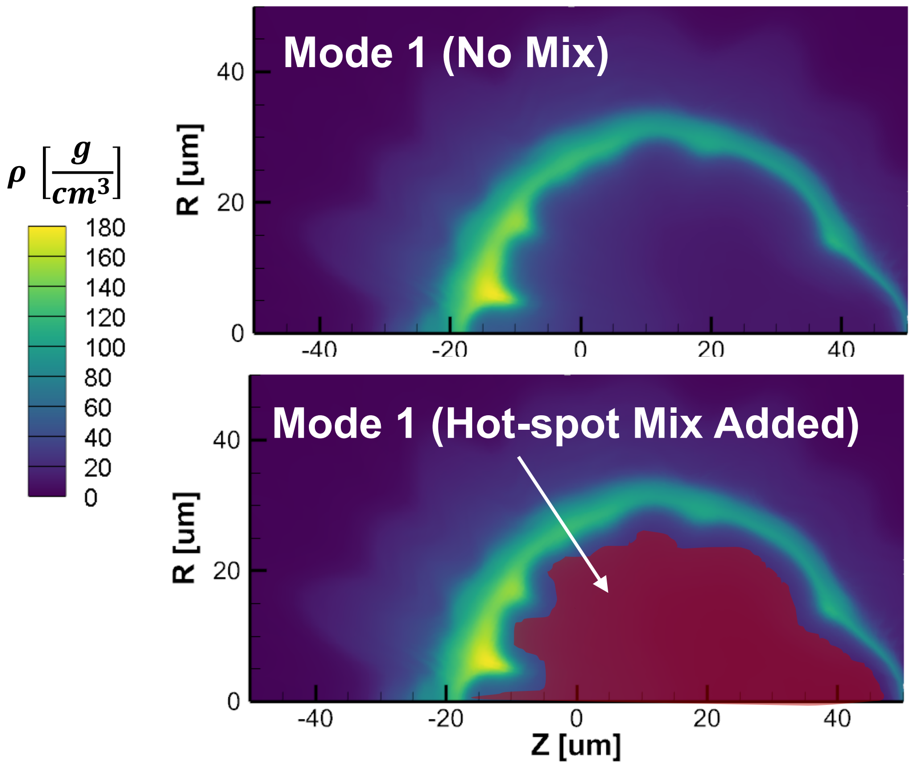
$$\frac{\left(\frac{Y_\nu}{Y_n}\right)_{exp}}{\left(\frac{Y_\nu}{Y_n}\right)_{\substack{Ice-Block \\ (No-Mix)}}} \approx \frac{\langle Z \rangle}{g_{H,FF}}\left[\langle Z^2 g_{FF} \rangle + 2\left(\frac{\chi_H}{kT_e}\right)\langle Z^4 g_{BF} \rangle\right]$$

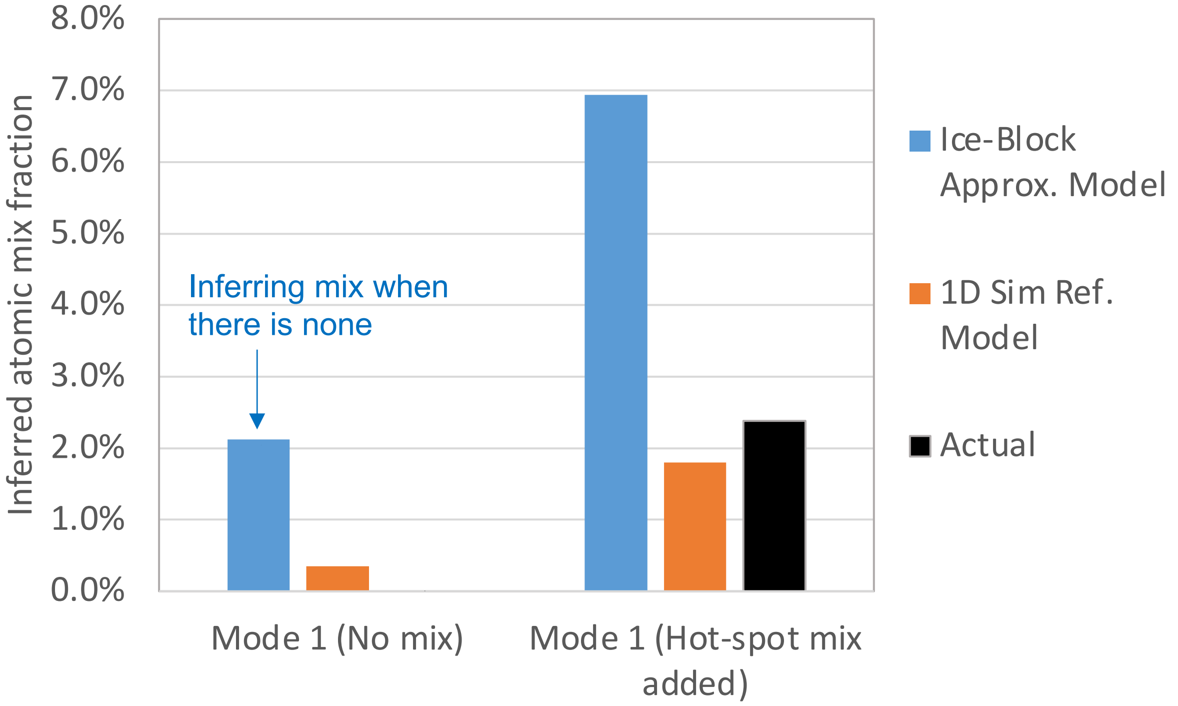
1D-simulation reference model:

$$\frac{\left(\frac{Y_\nu}{Y_n}\right)_{exp}}{\left(\frac{Y_\nu}{Y_n}\right)_{1D\ Sim.}} \approx \frac{\langle Z \rangle}{g_{H,FF}}\left[\langle Z^2 g_{FF} \rangle + 2\left(\frac{\chi_H}{kT_e}\right)\langle Z^4 g_{BF} \rangle\right]$$

- **Z dependency remains proportional to ratio between yield ratios and assumed uniform**

In tests with single-mode perturbation simulations, 1D reference model can offer more accurate mix estimates for implosions on OMEGA





More tests will be done with stronger and wider variety of perturbations

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