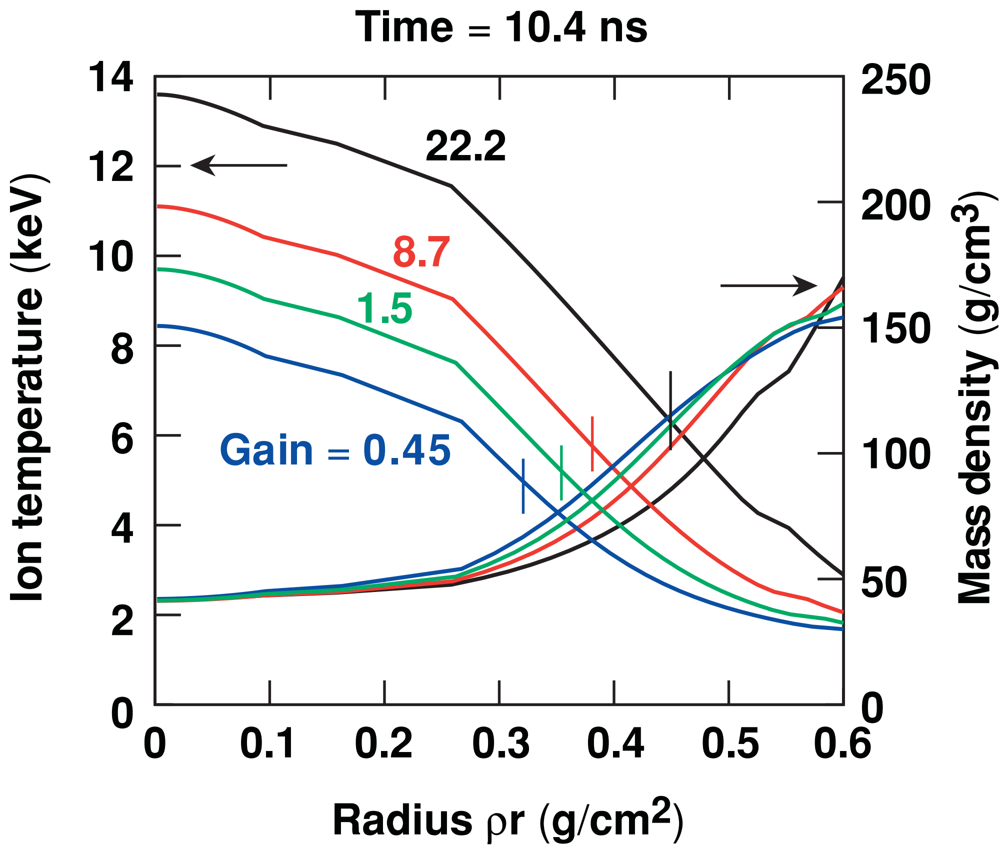
Modeling the Effects Mix at the Hot Spot Surface in 1-D Simulations of Cryogenic All-DT Ignition Capsule Implosions



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Summary

1-D modeling of a cryogenic, all-DT ignition capsule approximates the expected modifications of ignition by mix at the hot-spot surface

- The mix model includes the transport of target constituents, thermal energy, momentum, and turbulent energy within the mix region.
- Applying this model to an all-DT ignition capsule shows familiar mix effects on gain, the size of the hot spot, and their sensitivity to the known perturbation sources.
- The results of 2-D hydrodyamic simulation can be approximated reasonably well, considering the simplicity and economy of the 1-D model.

TC6081

Outline

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- The diffusive in-line mix model in *LILAC*
- Modification of pre-ignition conditions
- Consistency with 2-D simulations
- Application: gain sensitivity
- Conclusions

The mix model treats mix as a diffusion transport mechanism within the 1-D hydrocode *LILAC*

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- Mix regions evolve from initial surface and drive perturbations according to the saturable multimode perturbation model of Haan.[1]

- Perturbation growth rates are obtained from the Betti formula[2] for the ablation surface and from a variational method[3] for the vapor-ice interface with ablative stabilization at both surfaces.

- Mix transport is modeled as diffusion based on a diffusion coefficient obtained from the perturbation spectrum

$$\sigma = \alpha v_{mix} \lambda \frac{4(r_b - r)(r - r_s)}{(r_b - r_s)^2} \qquad v_{mix} = \frac{d}{dt}|r_b - r_s| \qquad \lambda^{-2} = \left\langle \left(\frac{\ell}{R}\right)^2 \right\rangle_\ell$$

- The hydrodynamic model includes turbulent pressure and viscosity P_T and Q_T.[4]

$$\rho \frac{dv}{dt} = -\frac{\partial}{\partial r}(P + Q + P_T + Q_T)$$

1. S. W. Haan, Phys. Rev. A 39, 5812 (1989).
2. R. Betti *et al.*, Phys. Plasmas 5, 1446 (1998).
3. K. O. Mikaelian, Phys. Rev., A 33, 1216 (1986).
4. C. E. Leith, UCRL-96036 (1986).

Mix motion energy is computed as turbulent energy in a "k-λ" model

- **Turbulent energy density k:**

$$P_T = \frac{2}{3}\rho k, \quad Q_T = -\frac{4}{3}\frac{\sigma\rho^2}{\beta_q}\frac{\partial v}{\partial m}, \quad \sigma = \upsilon_{mix}\lambda \qquad (\beta_q = 1.0)$$

- **Buoyant force as source of k:**

$$S = \max\left(u\frac{dv}{dt}, 0\right), \quad u = -\frac{\sigma}{\beta_m}\frac{\partial\rho}{\partial m} \qquad (\beta_m = 0.7)$$

- **Dissipation rate:**

$$\varepsilon = c_\varepsilon \frac{k^{3/2}}{\lambda} \qquad (c_\varepsilon = 0.09)$$

- **Evolution:**

$$\frac{dk}{dt} = \frac{\partial}{\partial m}\left(\rho^2 \frac{\sigma}{\beta_k}\frac{\partial k}{\partial m}\right) - (P_T + Q_T)\frac{\partial v}{\partial m} + S - \varepsilon \qquad (\beta_k = 0.715)$$

$$\frac{de_i}{dt} = \frac{\partial}{\partial m}\left(\rho^2 \frac{\sigma}{\beta_e}\frac{\partial e_i}{\partial m}\right) - (P + Q)\frac{\partial v}{\partial m} + \varepsilon - S + \ldots \quad \text{etc} \qquad (\beta_e = 0.9)$$

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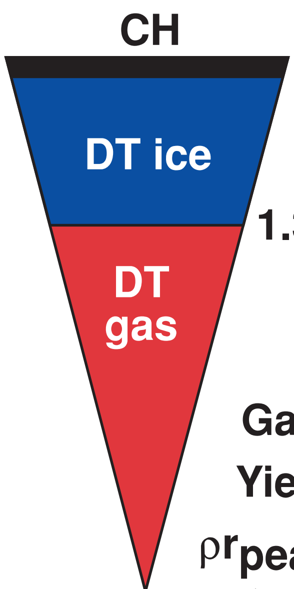
Mix-enhanced thermal transport reduces ignition yield by reducing the size and temperature of the hot spot

Baseline "all-DT"



1.5 MJ, α = 3

Gain: 45

Yield: 2.5×10^{19}

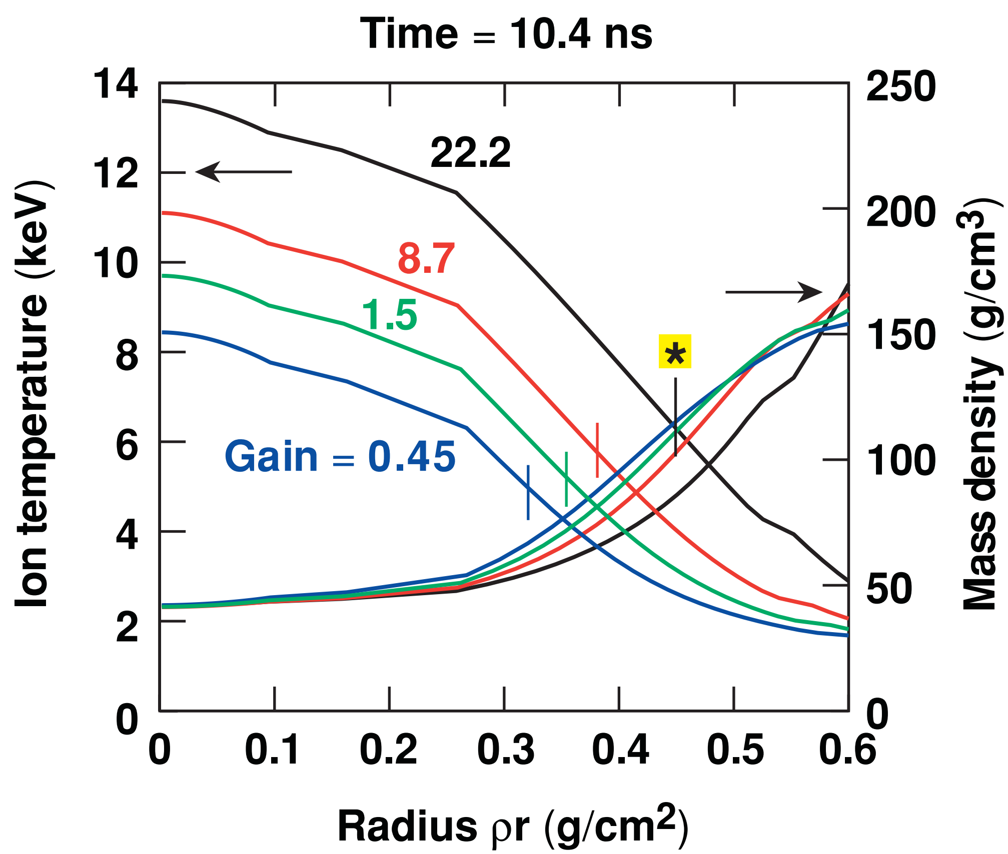
ρr_{peak}: 1300 mg/cm^2

$\langle T_i \rangle_n$: 30 keV

Hot-spot CR: 29

Peak IFAR: 60

* Radii at 1/10-maximum burn rate



R. Town, LLE Review 79, 121 (1999).

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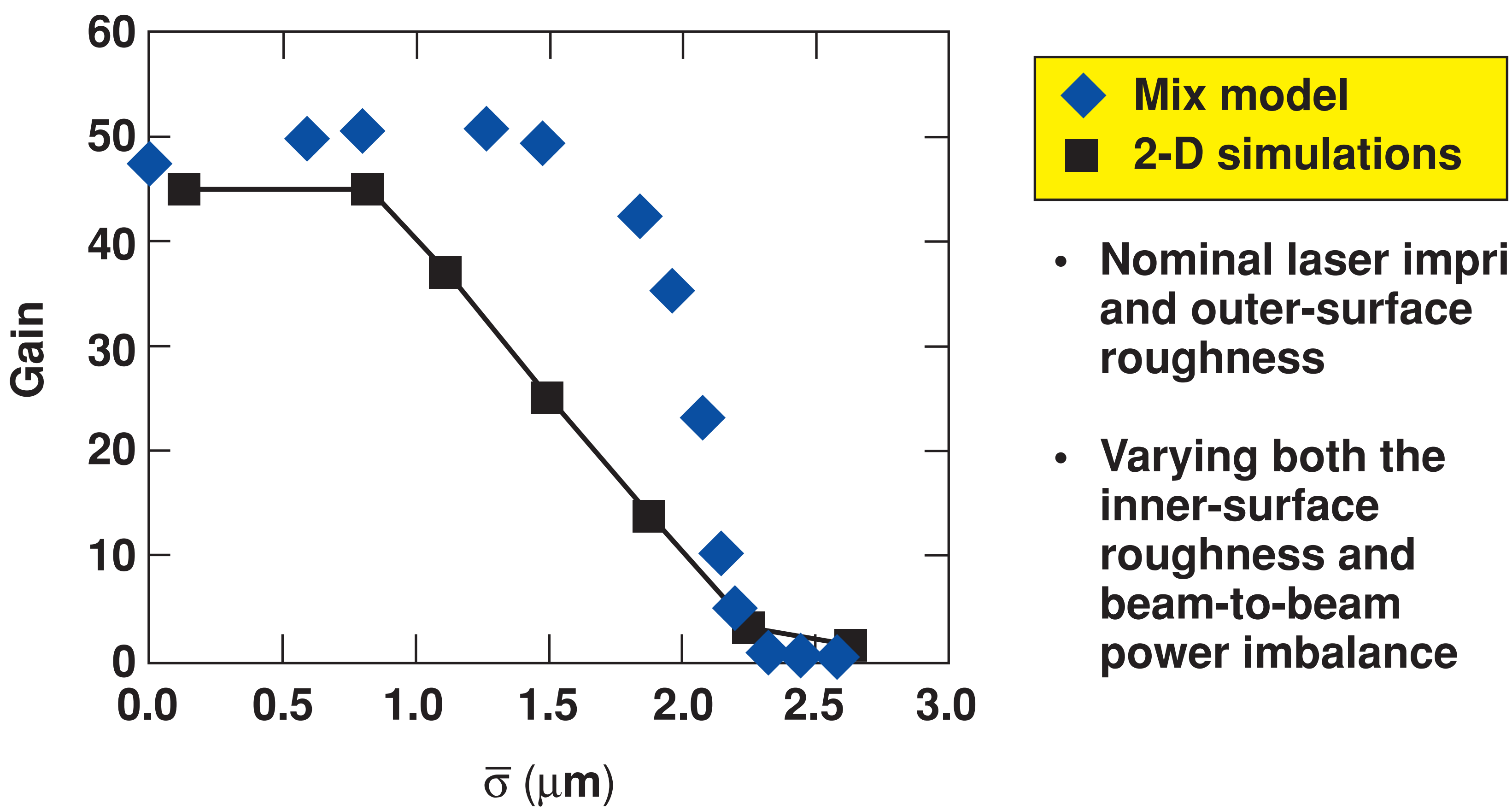
Gain reduction depends on an effective nonuniformity of the ice/vapor interface, similar to 2-D simulation results

$$\bar{\sigma}^2 = 0.06\ \sigma^2_{\ell<10} + \sigma^2_{\ell\geq 10}$$



- Nominal laser imprint and outer-surface roughness
- Varying both the inner-surface roughness and beam-to-beam power imbalance

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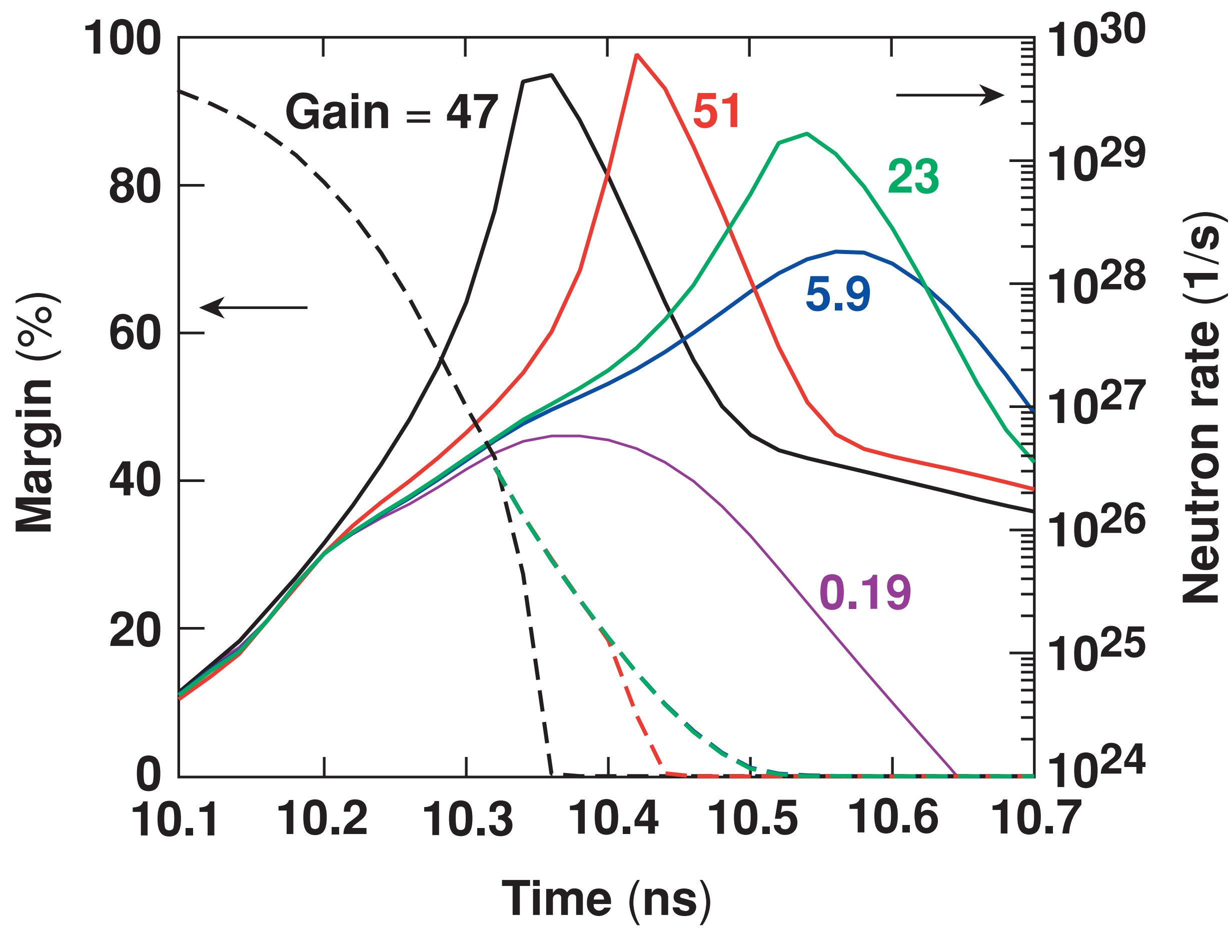
As expected, mix transport delays ignition and reduces the implosion energy margin

Margin ≡ percent of peak inward kinetic energy remaining at ignition



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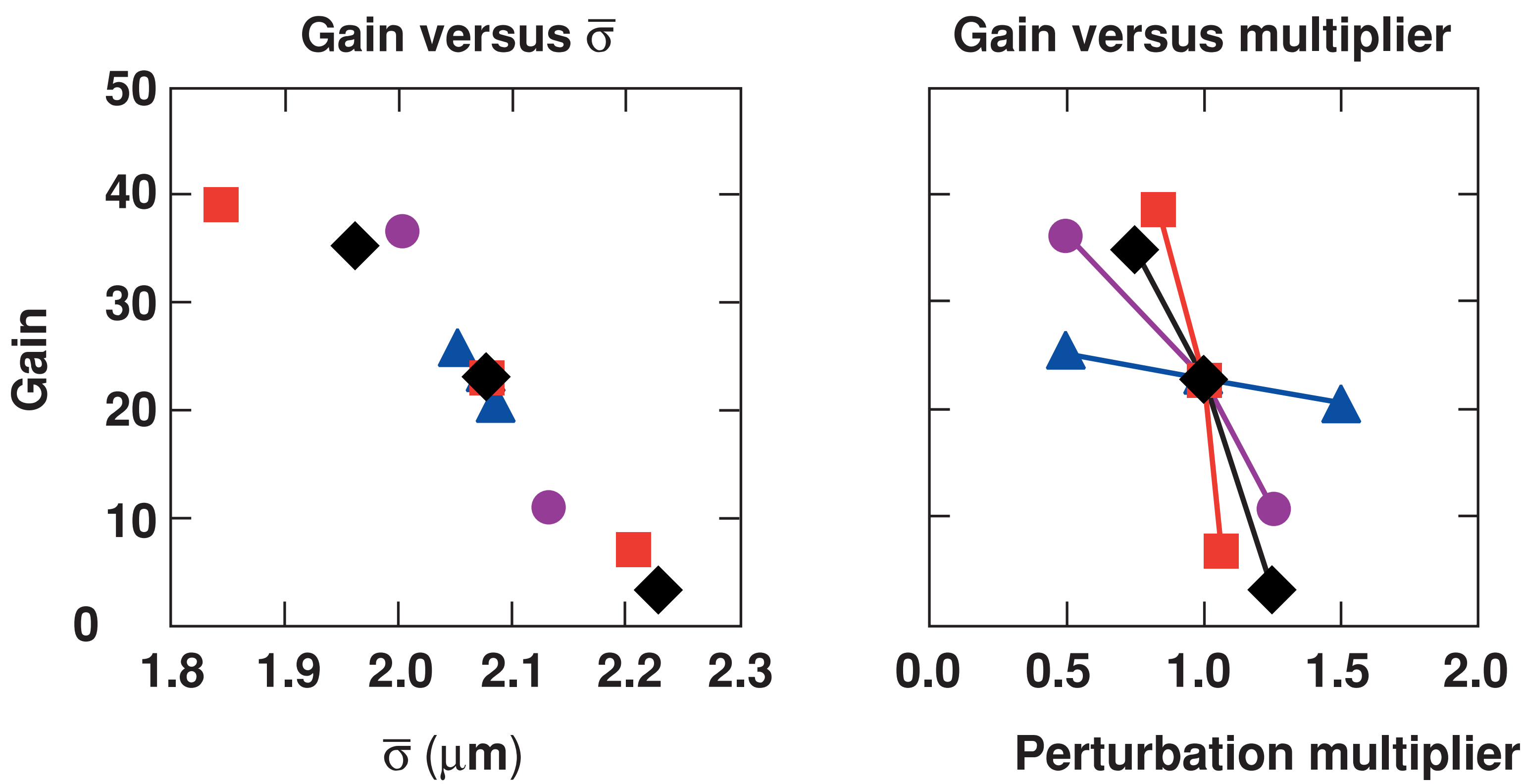
The sensitivity of the gain to variations in the perturbation sources indicates their relative importance



$$\bar{\sigma}^2 = 0.06\,\sigma^2_{\ell<10} + \sigma^2_{\ell\geq 10}$$

- ◆ Ice roughness 2-μm × ($\ell^{-0.75}$)
- ■ Beam imbalance 3%
- ▲ Outer roughness "NIF standard"
- ● Imprint, 1-THz, 1-color cycle, SSD

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