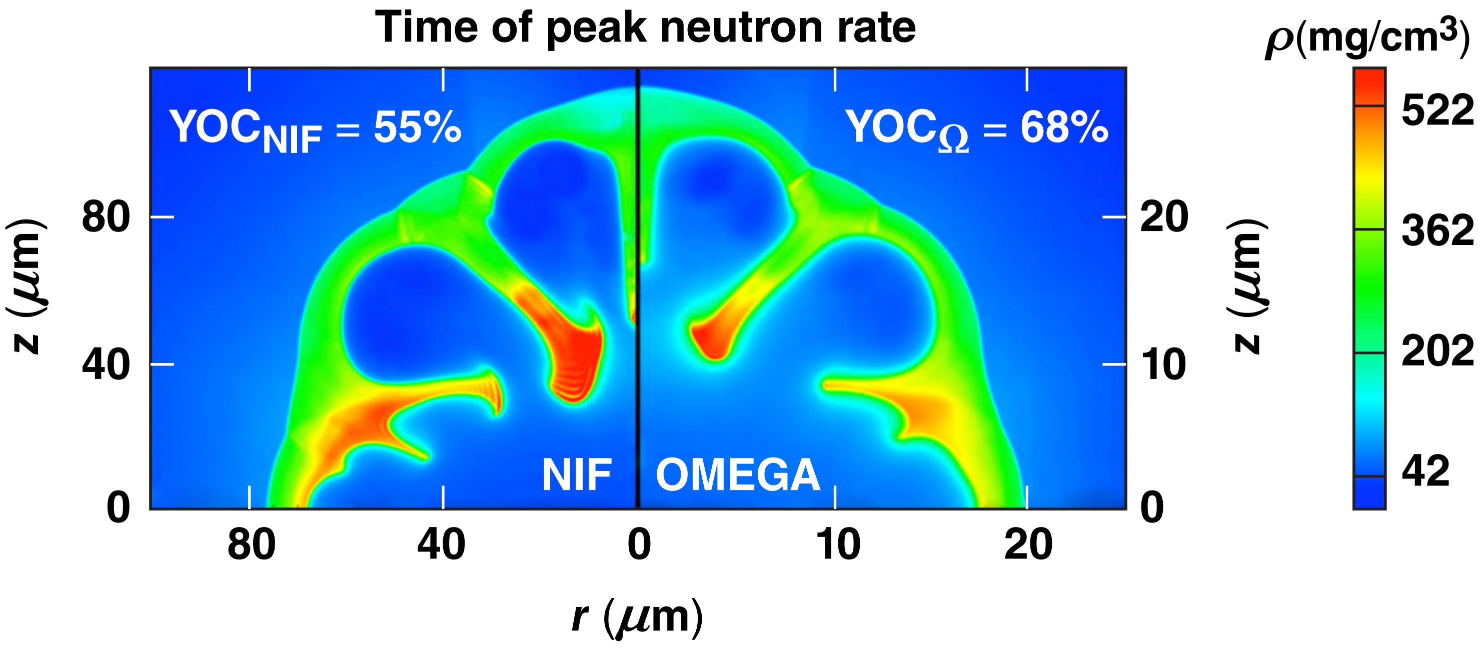
Hydrodynamic Scaling of the Deceleration-Phase Rayleigh–Taylor Instability



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Summary

The deceleration-phase Rayleigh–Taylor (RT) instability does not scale hydro-equivalently

- The nonscalability of the thermal transport in the hot-spot affects the deceleration-phase RT instability growth
- National Ignition Facility (NIF)-scale targets have lower mass ablation, resulting in higher RT growth factors and lower yield-over-clean (YOC)
- Simulations show that the YOC reduction with increasing target size caused by this effect is modest (~20% at implosion velocities of 430 km/s)

Collaborators

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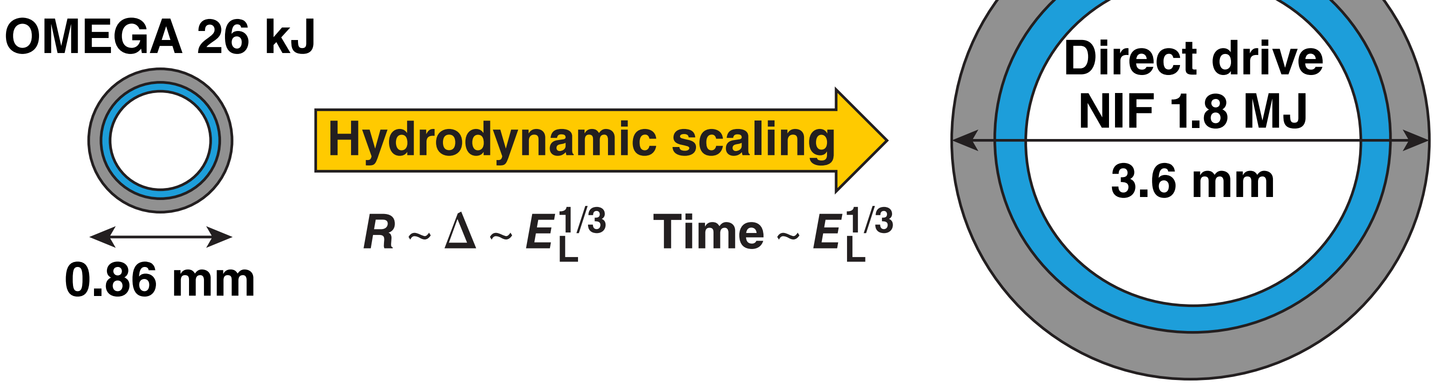
[2] also Department of Physics and/or Mechanical Engineering

OMEGA implosions are scaled hydro-equivalently to estimate performance on direct-drive symmetric NIF

Hydrodynamic equivalence*

Same V_i, α, I_L



OMEGA 26 kJ

0.86 mm

Hydrodynamic scaling

$R \sim \Delta \sim E_L^{1/3}$ Time $\sim E_L^{1/3}$

Direct drive NIF 1.8 MJ

3.6 mm

$$\text{YOC} = \left(\frac{\text{Yield}_{3\text{-D}}}{\text{Yield}_{1\text{-D}}}\right)$$

The generalized Lawson criterion scales as $\text{YOC}_{\text{no}\,\alpha}^{0.4}$

$$\chi_{3\text{-D}} \sim E^{0.37}\,\text{YOC}_{\text{no}\,\alpha}^{0.4}$$

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*C.D. Zhou and R.Betti, Phys. Plasma 14, 072703 (2007).

The deceleration-phase RT instability does not scale hydro-equivalently

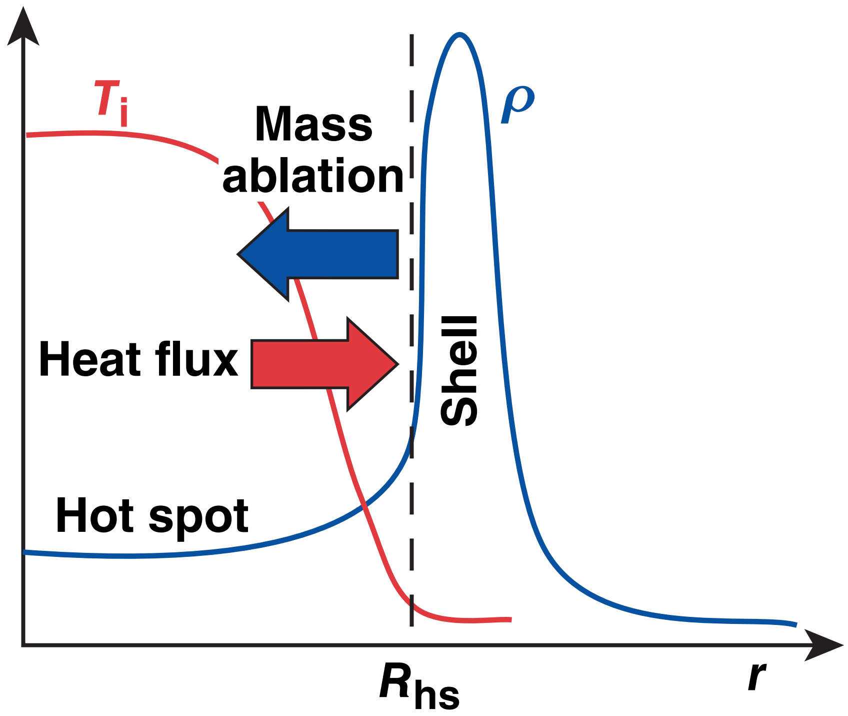
- Ablation velocity scales with the target size as

$$V_a \sim \frac{\kappa_0 T^{5/2}{}^{*}}{\rho_{sh} R} \sim 1/\sqrt{R}$$

- Larger targets have shorter density scale lengths because of lower ablation

$$N_e^{RT} = \alpha\sqrt{\frac{k\langle g\rangle t^2}{1+k\langle L_m\rangle}} - \beta\langle V_a\rangle t$$

$$\boxed{N_{NIF}^{RT} > N_{\Omega}^{RT}}$$



T_i

ρ

Mass ablation

Heat flux

Shell

Hot spot

R_{hs}

r

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*R. Betti *et al.*, Phys. Plasmas 9, 5 (2002);
V. Lobatchev and R. Betti, Phys. Rev. Lett. 85, 4522 (2000).

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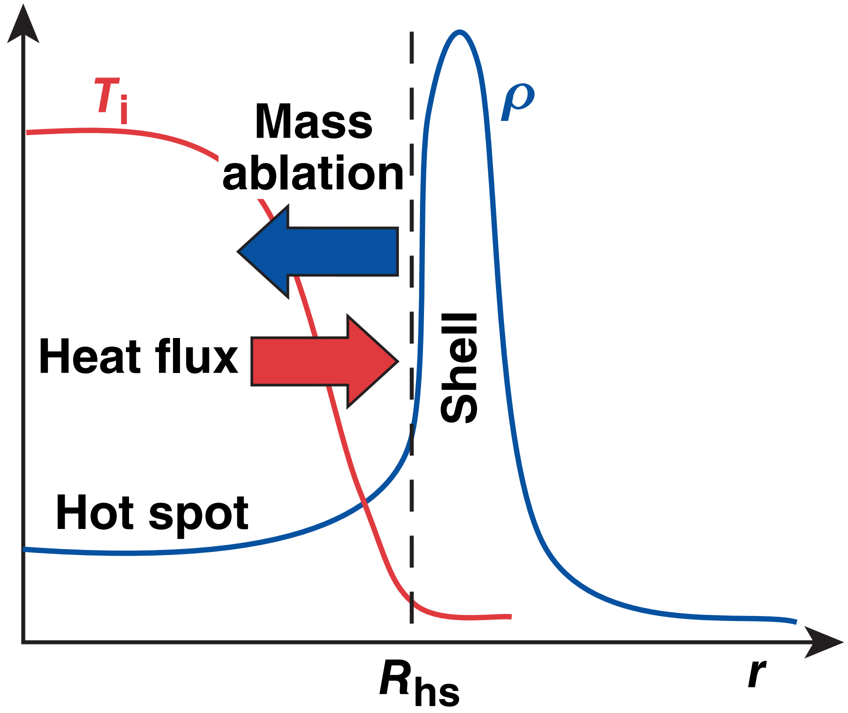

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Simulations are performed using a 2-D deceleration-phase hydrocode*,**

- The code imports 1-D *LILAC*† profiles at the end of the acceleration phase and simulates the deceleration phase in 2-D
- Features of the code
  - – second order Eulerian, with moving grid
  - – faster but with less physics than *DRACO*‡

Studies of the effects of thermal conduction are presented; radiation and alpha diffusion are not included.

V_i (km/s)	~430
Adiabat	~3.0

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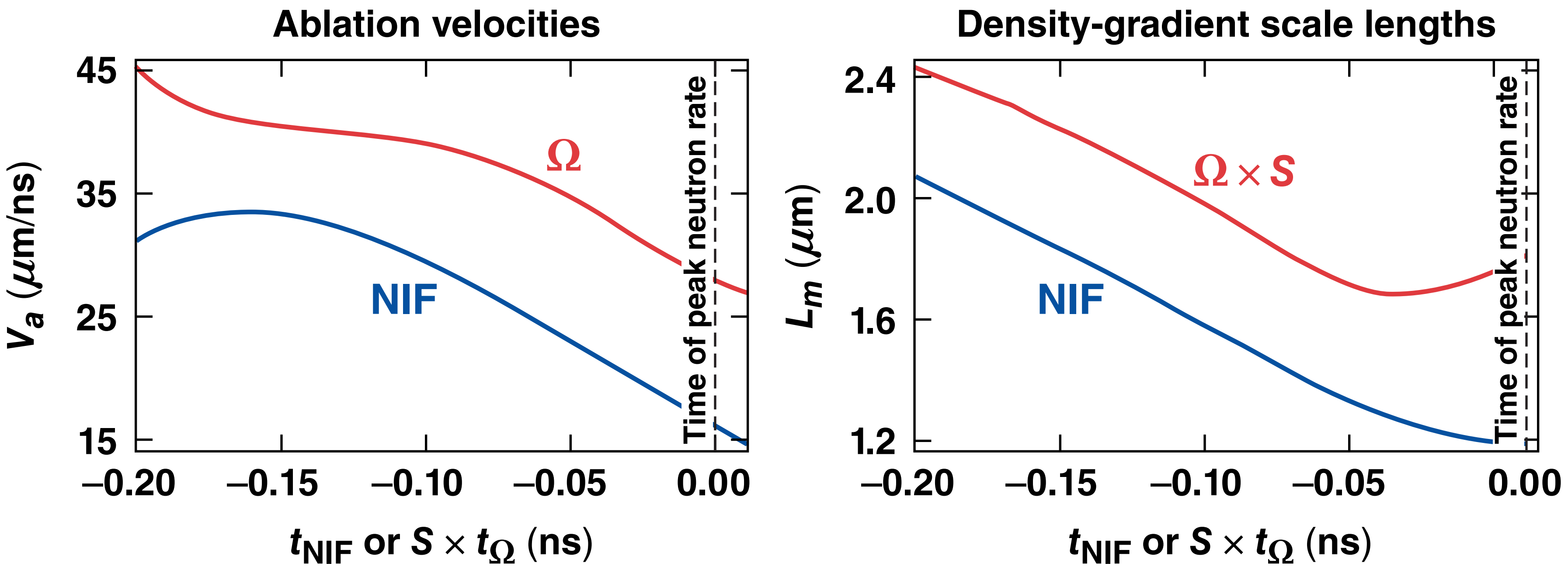
* A. Bose *et al*., Bull. Am. Phys. Soc. 57, 358 (2012).

** K. Anderson, R. Betti, and T. A. Gardiner, Bull. Am. Phys. Soc. 46, 280 (2001).

† J. Delettrez *et al*. Phys. Rev. A 36, 3926 (1987).

‡ P. B. Radha *et al*., Phys. Plasmas 12, 032702 (2005).

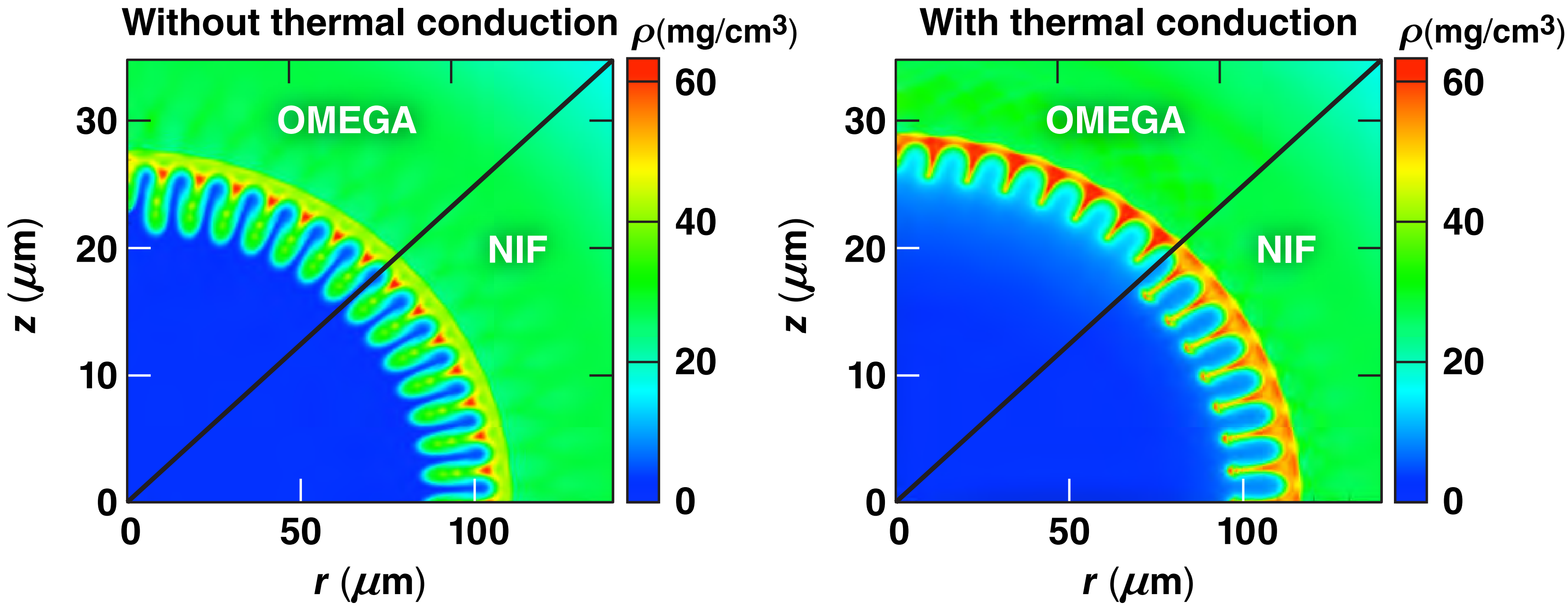
The ablation velocities and relative density-gradient scale lengths on OMEGA are greater than on the NIF



$$\boxed{S \equiv \left(\frac{R_{NIF}}{R_\Omega}\right) \sim 4}$$

Thermal transport in the hot spot makes the deceleration phase nonscalable

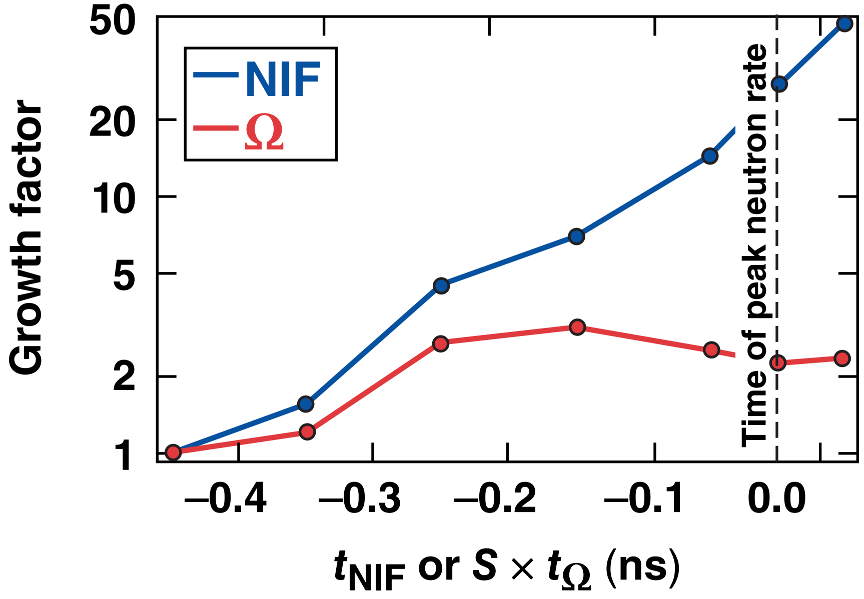
- Density at hydro-equivalent times showing $\ell = 60$ growth



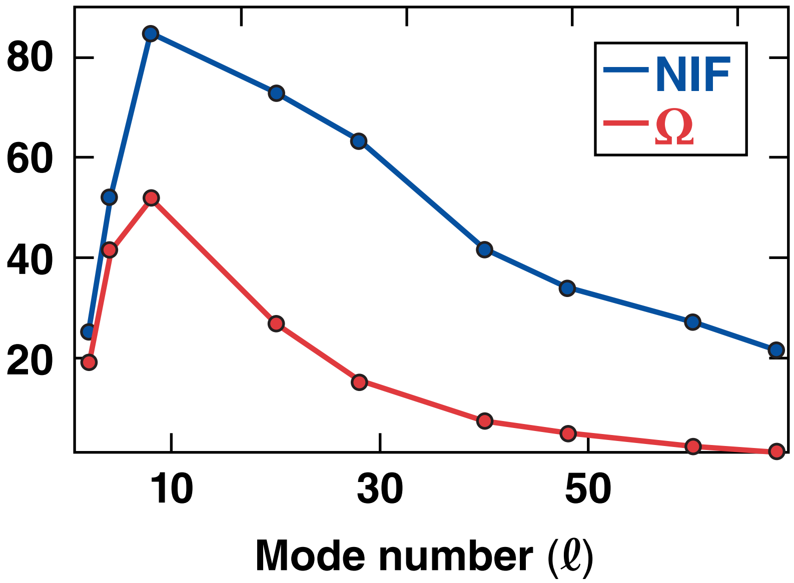
Classical deceleration-phase RT is exactly hydro-equivalent; thermal transport in the hot spot is nonscalable.

The deceleration-phase linear growth factors on the NIF are greater than on OMEGA for scaled initial perturbations

Time evolution of deceleration RT growth factor for mode $\ell = 60$

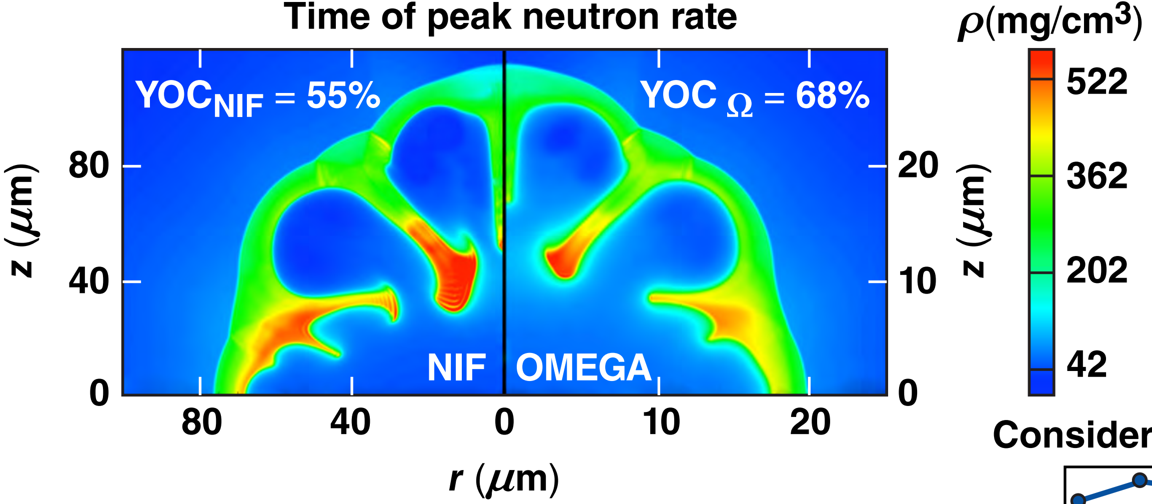


Deceleration RT growth factors



$$S \equiv \left(\frac{R_{\text{NIF}}}{R_\Omega}\right)$$

Multimode simulations show that differences in the deceleration phase of hydro-equivalent implosions have a modest effect of the YOC ratio



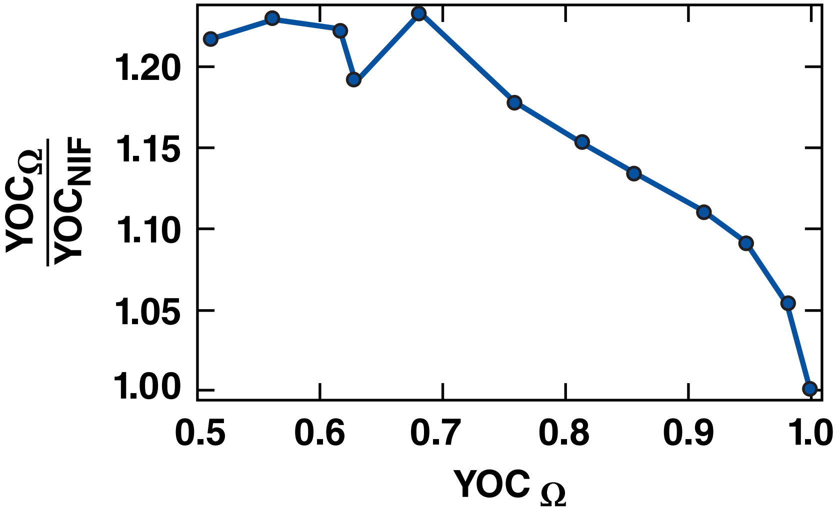
$\Delta V/V_{imp}$ % = 0.015

$10 < \ell < 60$ with ℓ^{-2} spectrum

- **Hydro-equivalent ignition condition on OMEGA***

$$\chi_{\Omega} \approx 0.2\left(\frac{YOC_{\Omega}}{YOC_{NIF}}\right)^{0.4}$$

Considering this effect only, $YOC_{\Omega} > YOC_{NIF}$



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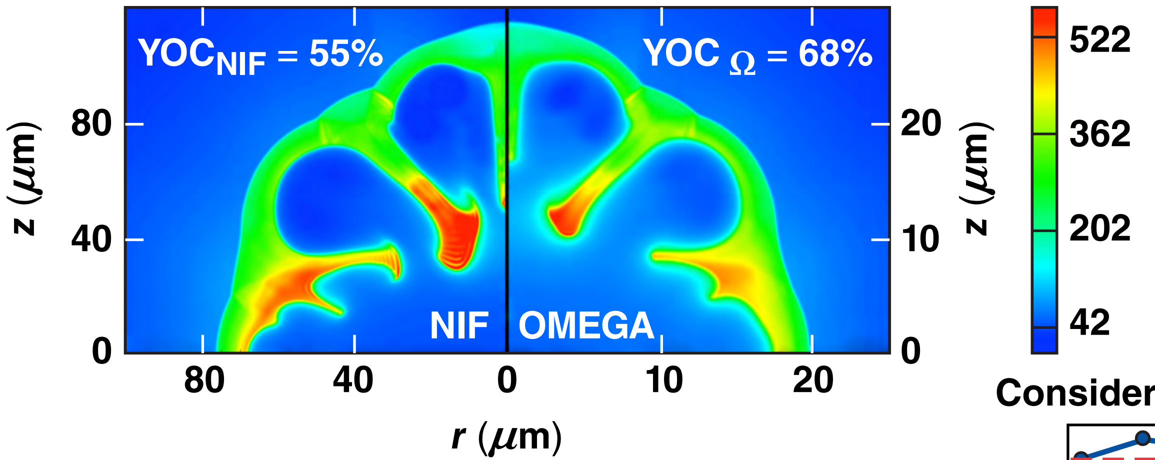
*The effect of laser imprinting on the scaling of the $YOC_{no\ \alpha}$ is considered in R. Nora, GI3.00002, this conference (invited).

Multimode simulations show that differences in the deceleration phase of hydro-equivalent implosions have a modest effect of the YOC ratio

Time of peak neutron rate



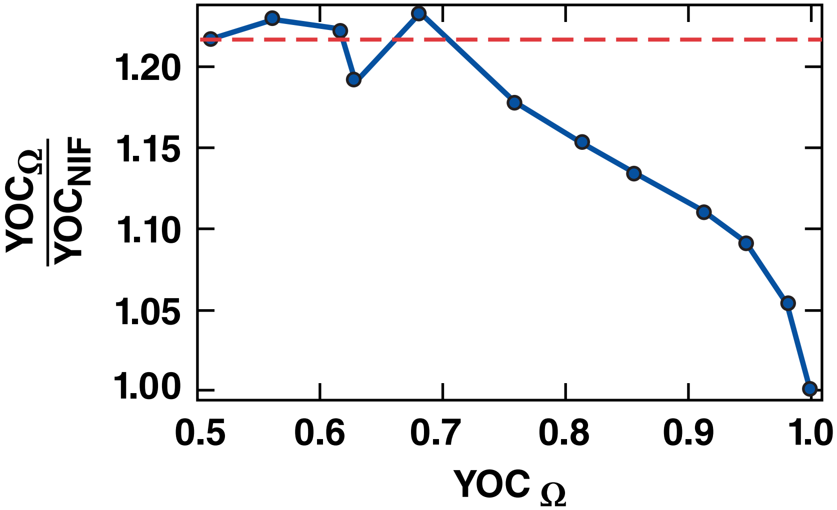
$\Delta V/V_{imp}$ % = 0.015

$10 < \ell < 60$ with ℓ^{-2} spectrum

- **Hydro-equivalent ignition condition on OMEGA***

$$\chi_\Omega \approx 0.2\left(\frac{YOC_\Omega}{\underset{\substack{\uparrow\\1.22}}{YOC_{NIF}}}\right)^{0.4} \approx 0.21$$

Considering this effect only, YOC$_\Omega$ > YOC$_{NIF}$



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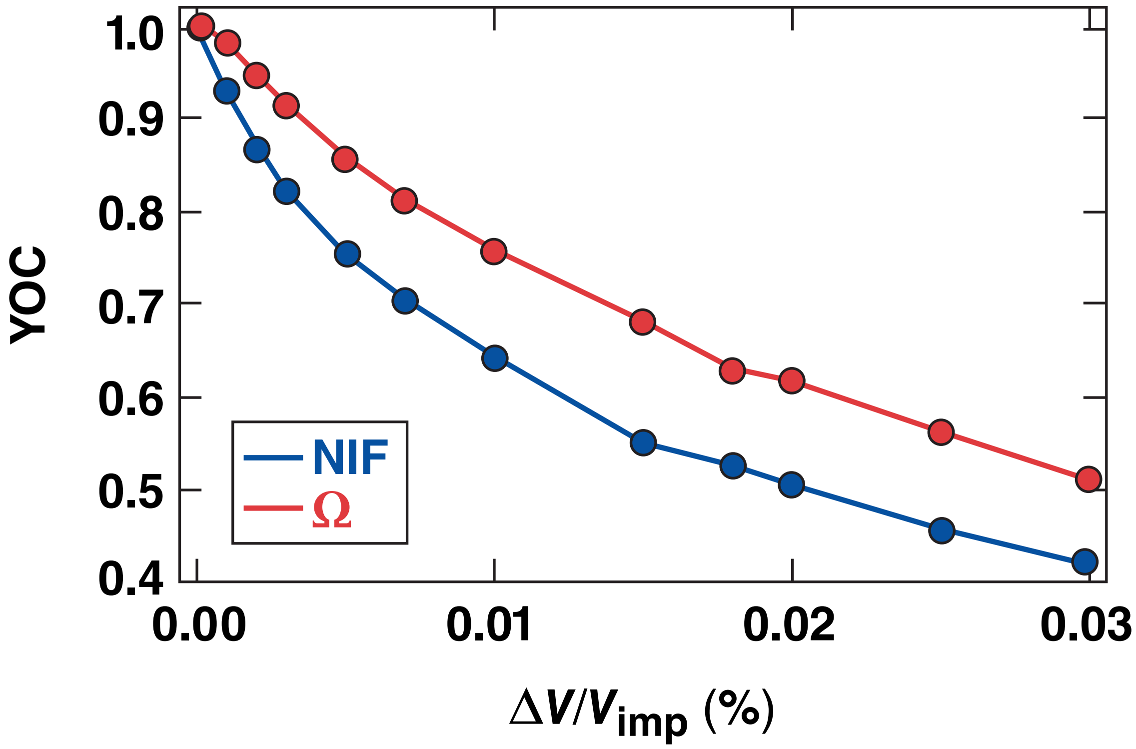
The difference in deceleration RT growth factors are less important at lower implosion velocities*

V_i (km/s)	~430
Adiabat	~3.0



- The effect of mass ablation on the deceleration phase Rayleigh–Taylor scales with the implosion velocity

$$\boxed{\frac{kV_a}{\sqrt{kg}} \sim V_{imp}}$$

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