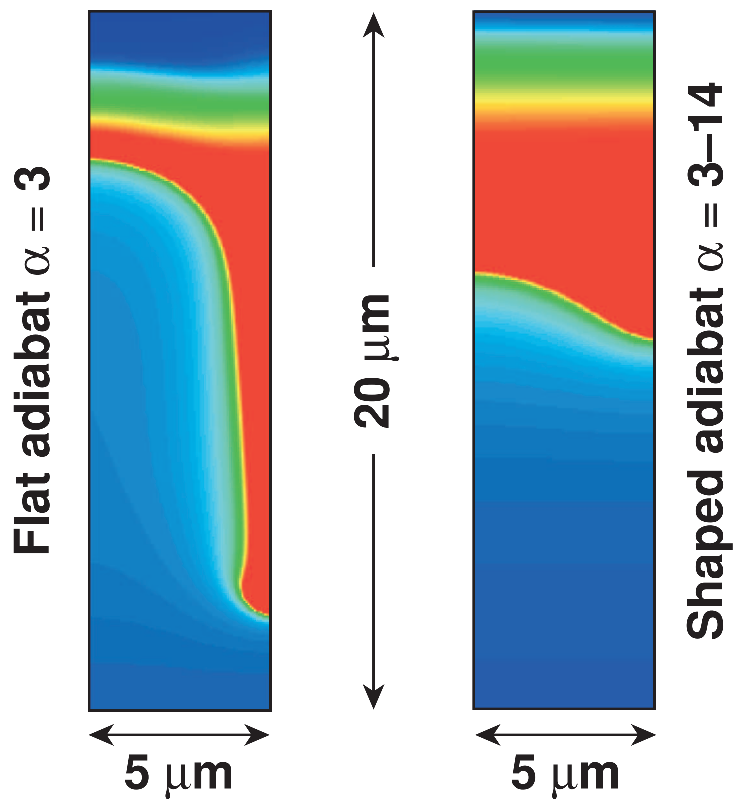
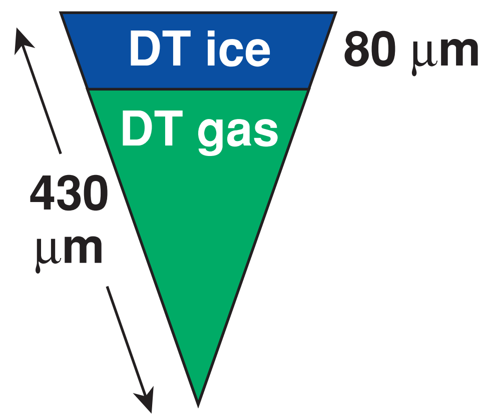
Theory of Laser–Induced Adiabat Shaping



Laser energy: 30 kJ
Neutron yield: 3×10^{14}



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Collaborators

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Outline

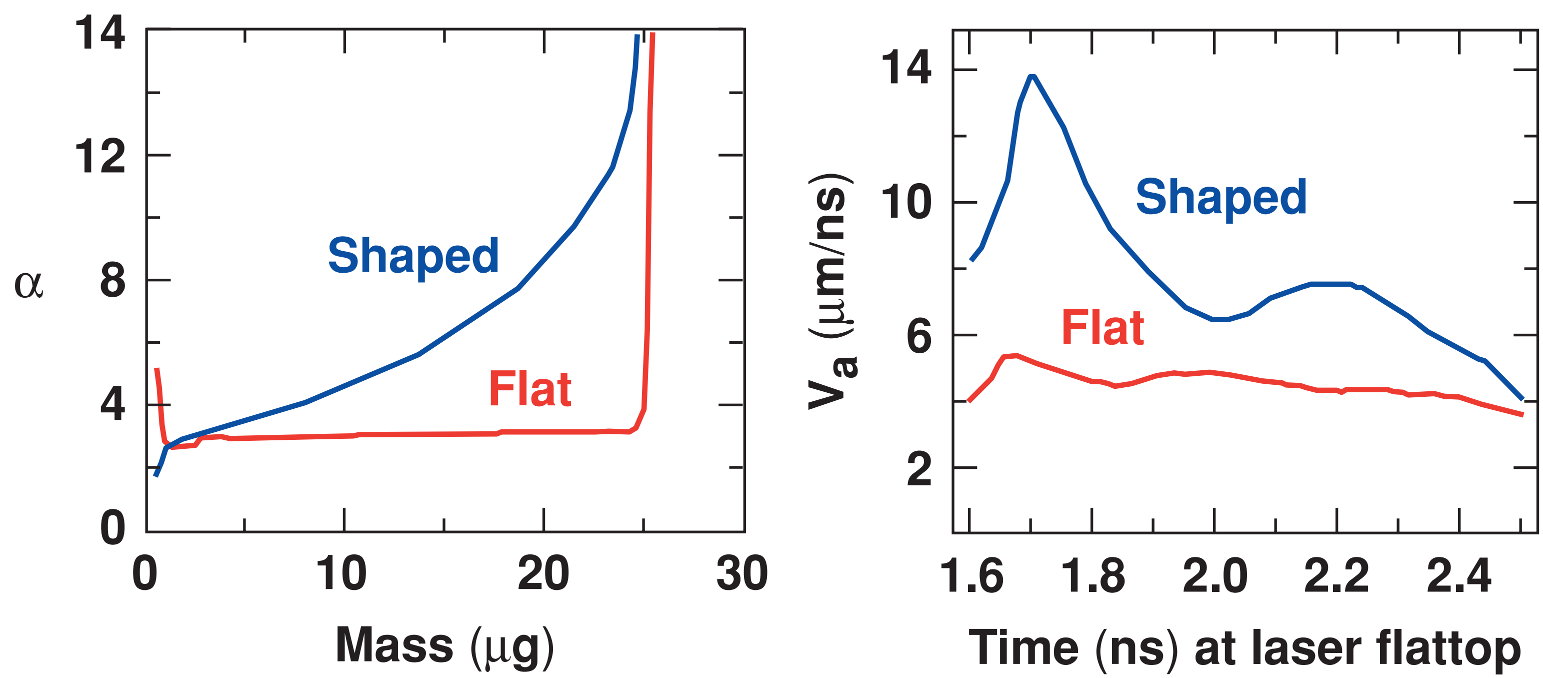
Shaping the adiabat improves the stability of the implosion

- The Rayleigh–Taylor instability in adiabat-shaped targets
- The convective instability driven by adiabat gradients
- Comparison between theory and simulations

- Other presentations on adiabat shaping at this meeting:
  V. Goncharov RI1.004
  J. Perkins FO2.014
  J. Knauer FO2.012
  K. Anderson FO2.011
  T. Collins UO2.003

The reference capsules are OMEGA 30-kJ cryo targets with a flat ($\alpha = 3$) or a shaped ($\alpha = 3$–14) adiabat

- Adiabat: $\alpha \equiv P/P_{Fermi}$, Ablation velocity: $V_a \sim \alpha^{3/5}$.
- The shaping is performed with a 50-ps, 2.4-TW prepulse.



- Standard theory: larger ablation velocity → lower RT growth rates

$$\gamma = 0.94\sqrt{k < g >} - 2.7\, k < V_a >$$

TC6039

The linear theory of the ablative RT with adiabat gradients can be easily carried out for short wavelengths

UR LLE

- Short-wavelength (kd>1) eigenfunction equation in the overdense shell

$$\partial_{xx}\tilde{v}_n - k^2\hat{h}^2\tilde{v}_n \approx 0 \qquad \hat{h}^2 \approx 1 - \frac{3\,g}{5\,L_\alpha\left(\gamma + k\hat{h}V_a\right)^2}$$

L_α = adiabat gradient scale length

- Eigenfunction: $\tilde{v}_n \sim \exp\left(-k\hat{h}x\right)$

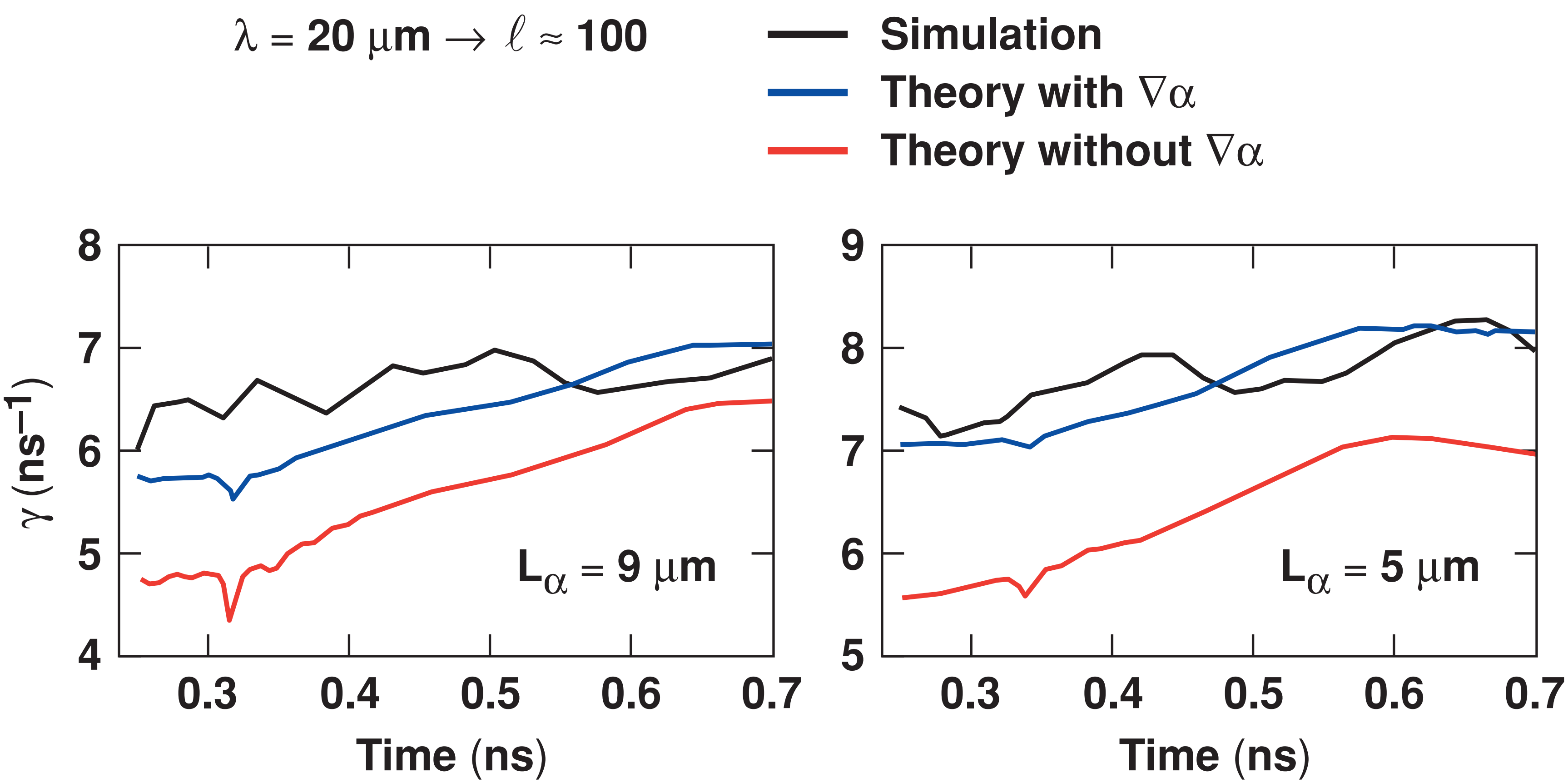
- Dispersion relation

$$\gamma^2\hat{h} + \gamma k V_a\left(1+\hat{h}\right)^2 + k^2 V_a^2\left(\hat{h}+\hat{h}^2\right) - A_T\left(kg - k^2 V_a V_b\right) \approx 0$$

V_b: Blowoff velocity

For a fixed V_a, the adiabat gradients increase the RT growth rates

$\lambda = 20\ \mu m \rightarrow \ell \approx 100$



- IMPORTANT: without adiabat shaping $\rightarrow$ low $V_a \rightarrow \gamma \approx 9\ ns^{-1}$

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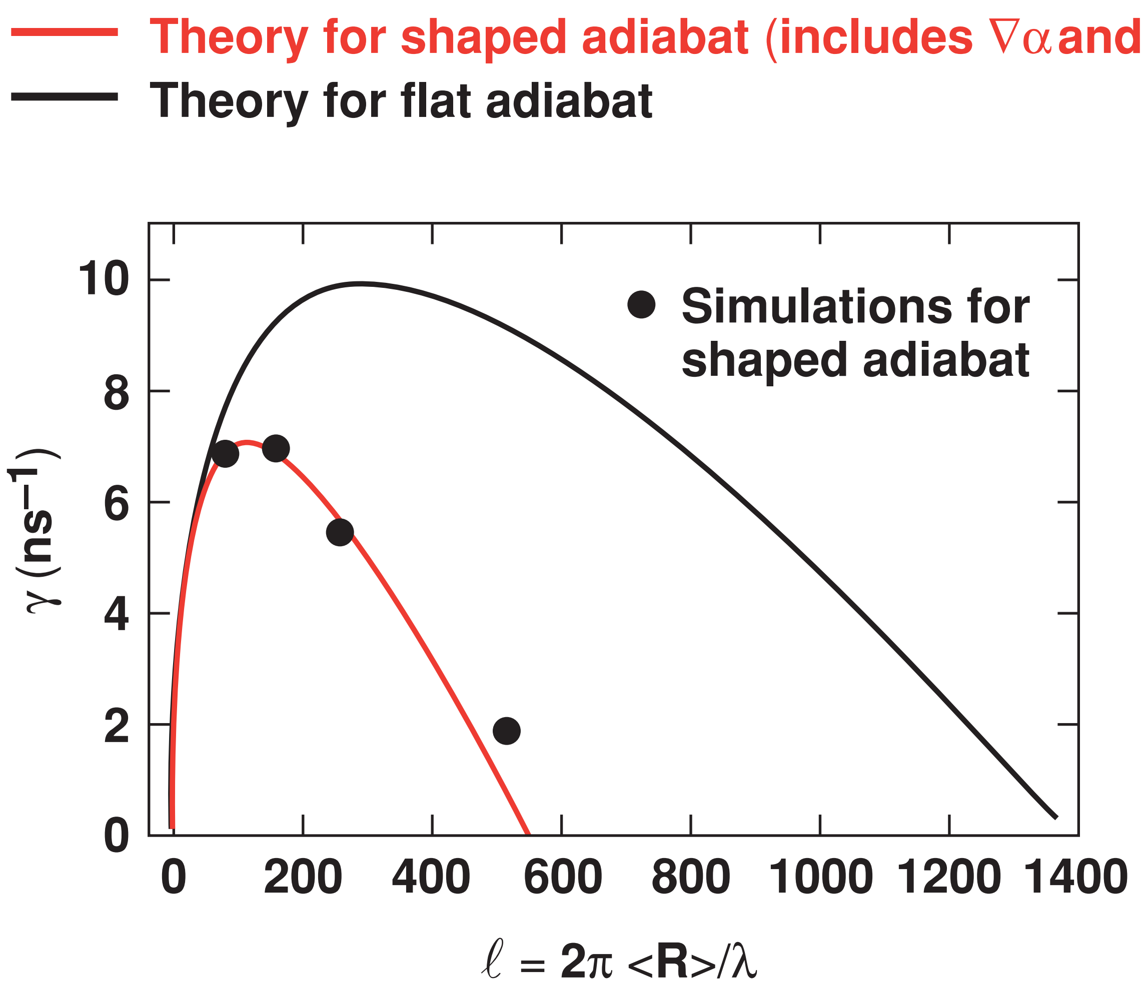
Despite the destabilizing effects due to $\nabla\alpha$, the RT growth is significantly reduced by the faster ablation



OMEGA 30 kJ

Flat $\rightarrow \alpha = 3$
Shaped $\rightarrow \alpha = 3\text{–}14$

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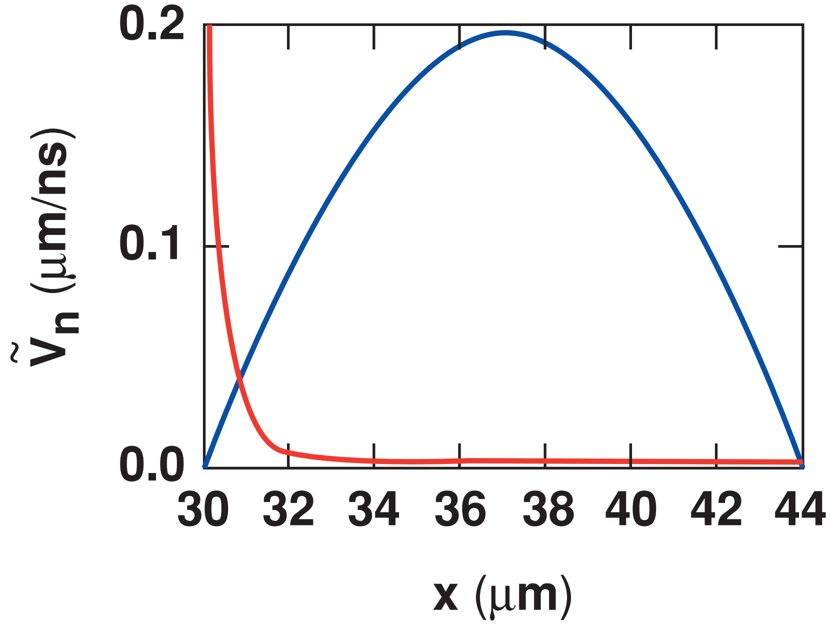
A convective instability is present in adiabat-shaped targets

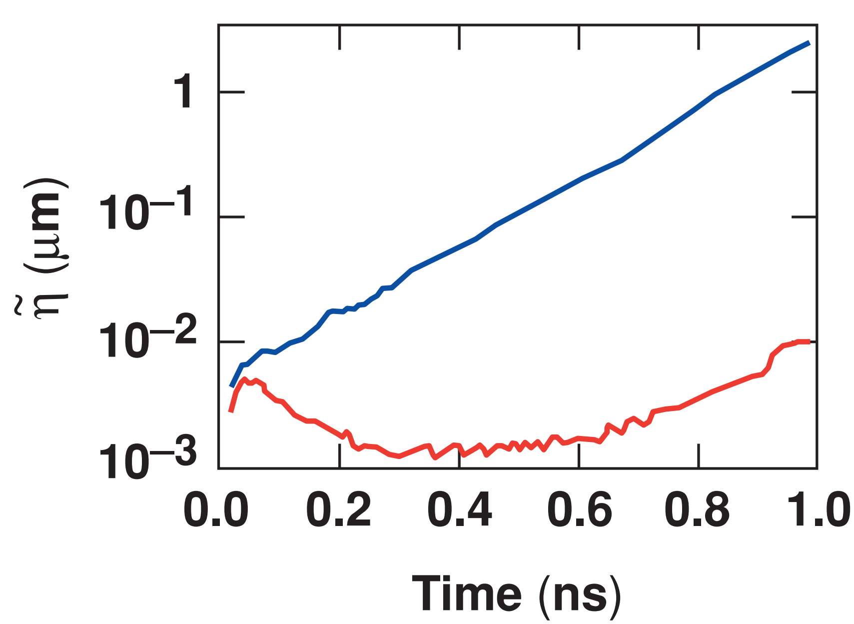
Vortex → $\tilde{V}_n \sim \sin(\pi x/d_{shell})$; $\tilde{V}_t \sim \cos(\pi x/d_{shell})$

RT mode → $\tilde{V}_n \sim \exp(-kx)$

Initial perturbation



Ablation front distortion



- Target: α = 3–14; perturbation: λ = 3 μm

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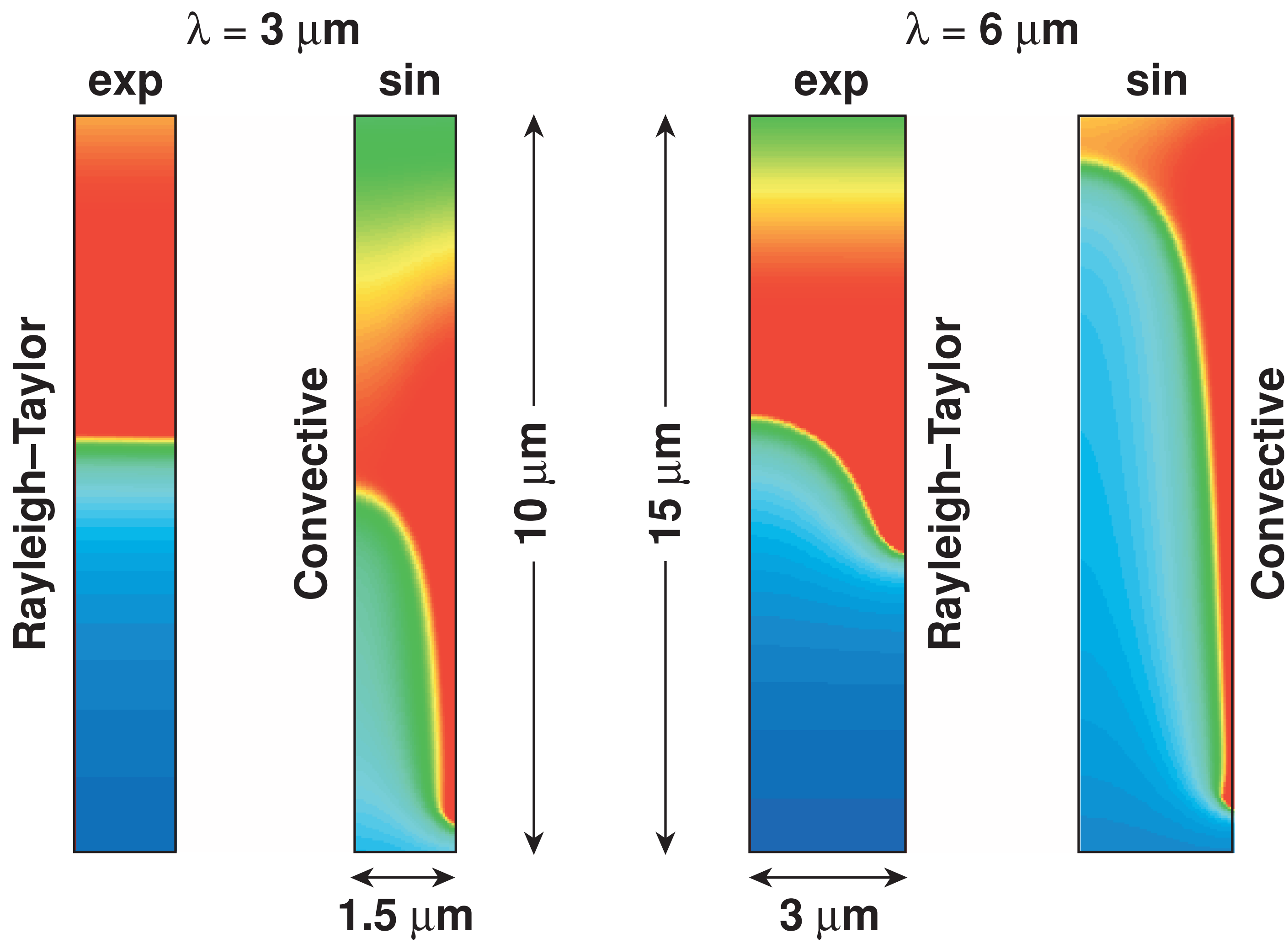
After 1 ns the convective instability leads to a large target distortion relative to the RT



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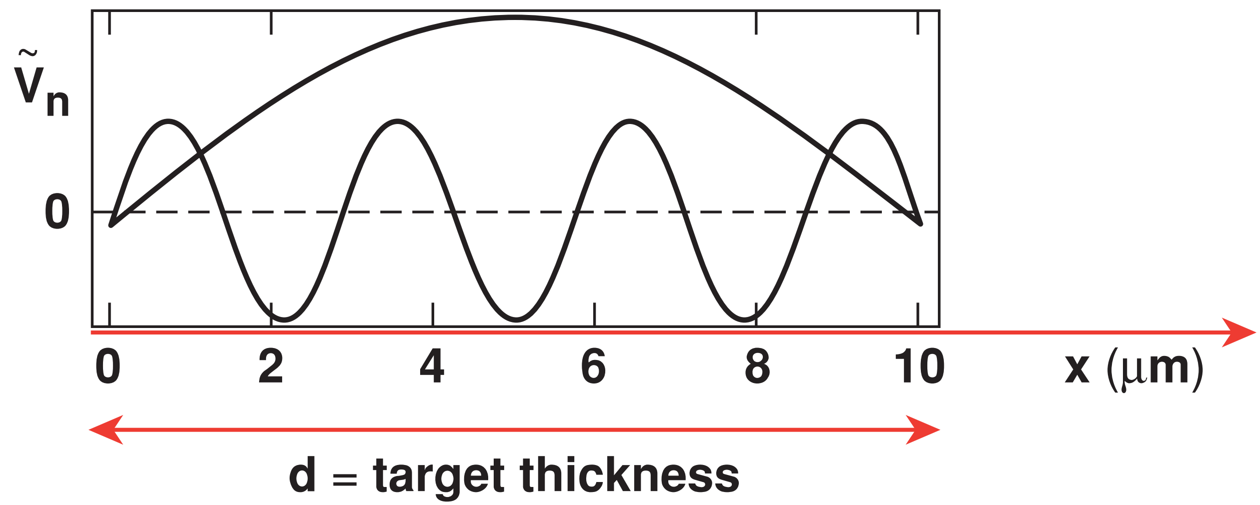
The classical theory of the convective instability yields internal modes that do not perturb the surfaces

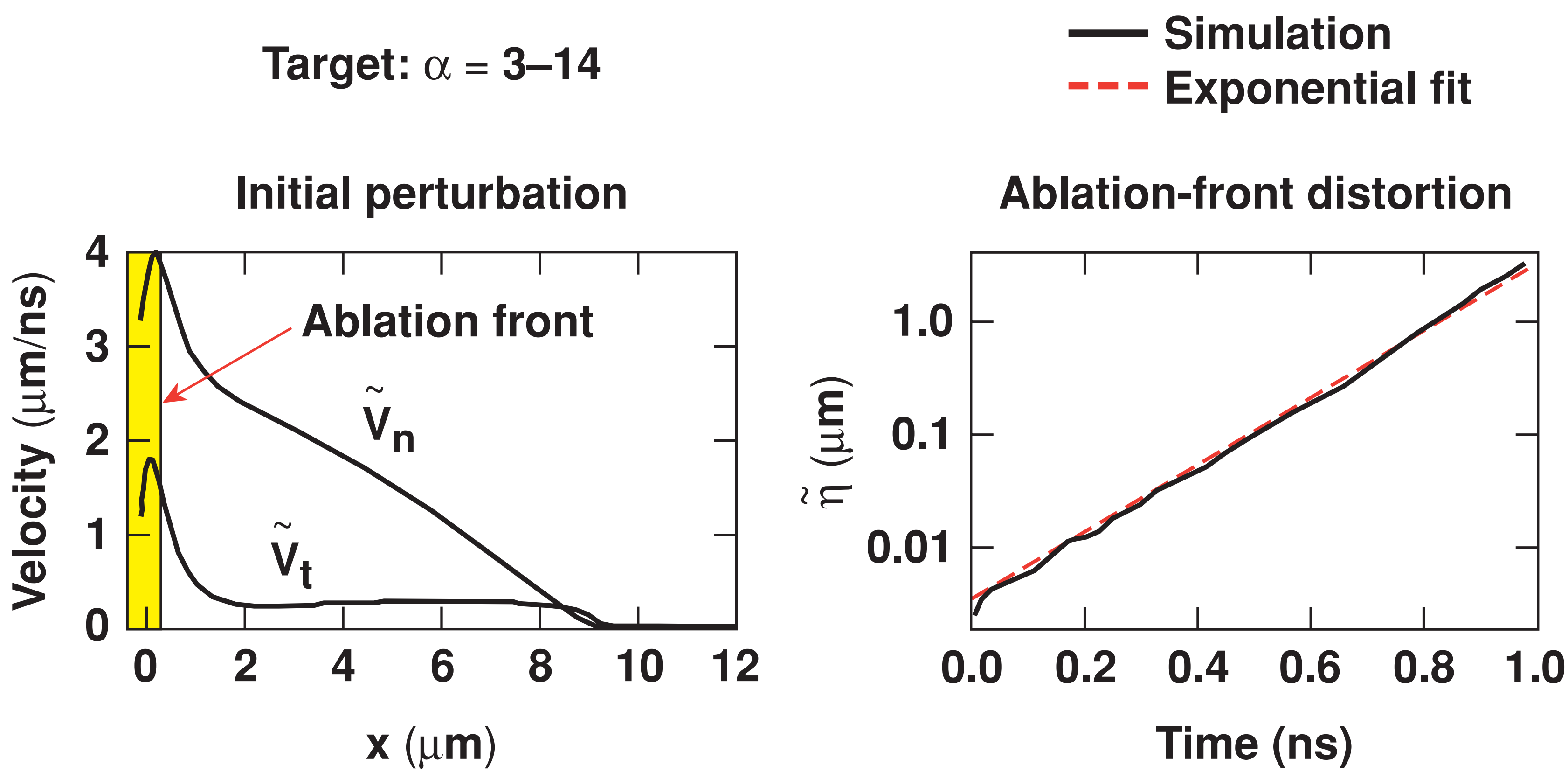


- **Eigenfunction:** $\tilde{v}_n \sim \sin(n\pi x/d) \quad n = 1, 2, 3 \ldots$

- **Growth rates:** $\gamma \approx \sqrt{\dfrac{3g}{5L_\alpha\left[1+(n\pi/kd)^2\right]}} \Rightarrow \gamma_{max}^{n=1}(kd >> 1) \approx \sqrt{\dfrac{3g}{5L_\alpha}}$

TC6045

For a finite ablation velocity, the convective mode couples to the RT mode distorting the ablation front



$$\gamma_{cl} \approx \sqrt{\frac{3\,g}{5\,L_\alpha}} \approx 6\,\text{ns}^{-1}, \quad \gamma_{fit} \approx 7\,\text{ns}^{-1}$$

TC6046

Real velocity perturbations are induced by rippled shocks with Bessel spatial distributions; the seeded convective modes grow slowly

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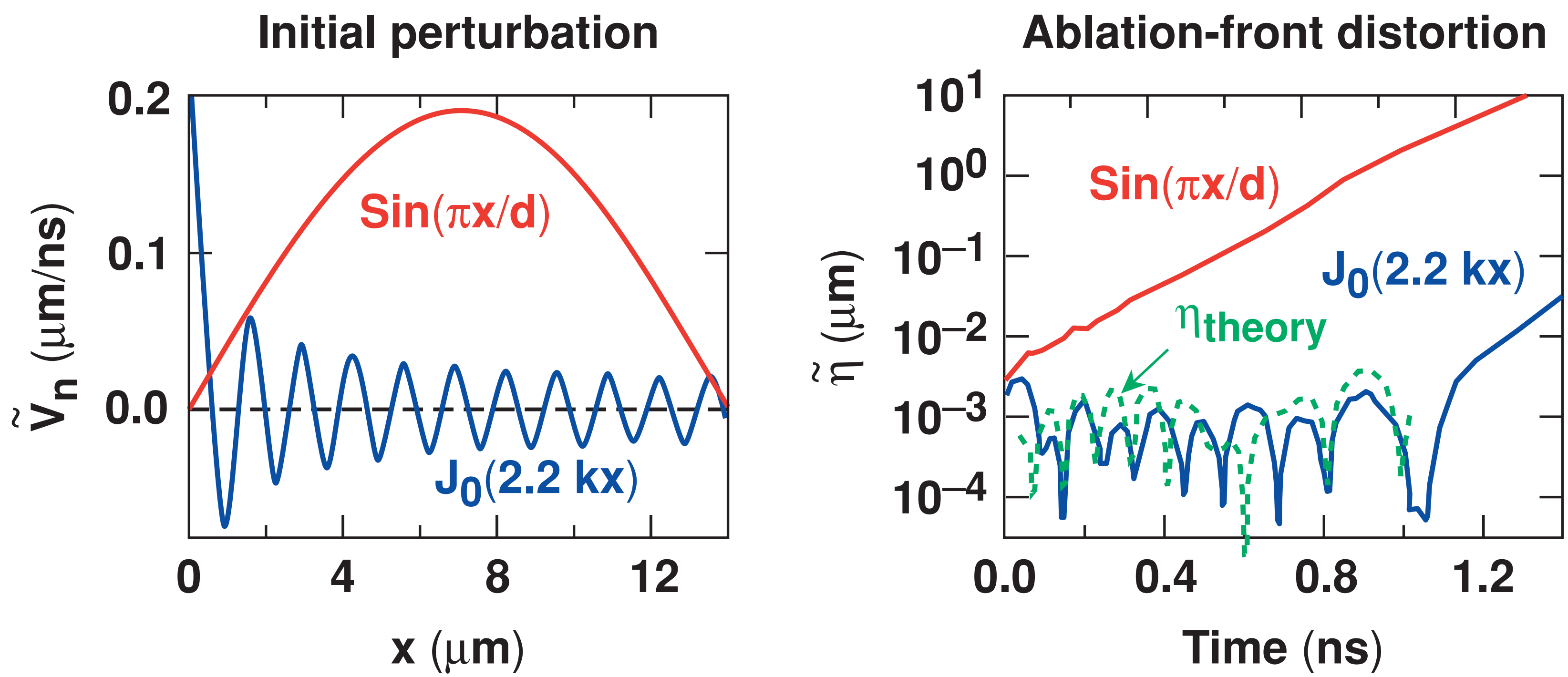

$$J_0(2.2\ kx) \sim \sin(2.2\ kx) \rightarrow \text{seeds for } \sin(n\pi x/d) \rightarrow n = (2.2\ kd)/\pi >> 1$$

$$\gamma \approx \frac{\gamma_{max}}{\sqrt{6}} \approx 2\ \text{ns}^{-1} \Rightarrow \tilde{\eta}_{theory} \approx \int_0^t J_0(2.2\ kV_a t) e^{2t} dt$$

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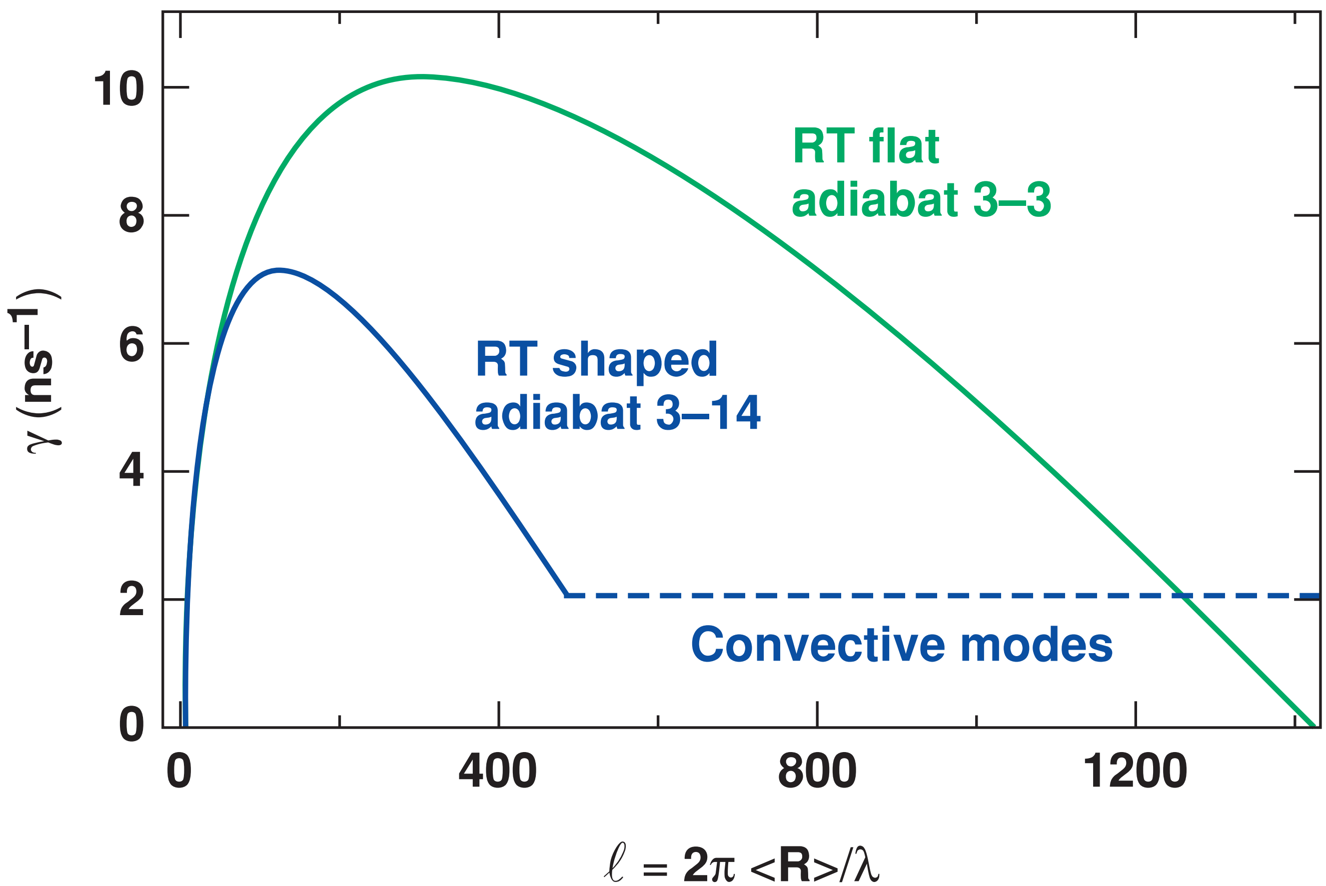
Conclusion

OMEGA cryo targets are strongly stabilized by adiabat shaping if fast-global-convective modes are not seeded



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