# Numerical Study of Feed-out of Short-Wavelength Rear-Surface Perturbations in Planar Targets

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The propagation of a small, short-wavelength perturbation from the back to the front surface of a laser-accelerated planar foil is investigated numerically, the foil being considered as an ideal gas. The front surface is initially flat, while the back surface is rippled. After the initial shock reaches the back surface, the rippled reflected rarefaction wave propagates toward the front and thus transfers the perturbation from the back surface to the front surface. Once the front becomes rippled, the Rayleigh–Taylor instability is seeded and the perturbation grows exponentially in time. An approximate solution of linearized compressible flow equations can be found when the ripple wavelength is longer than the thickness of the compressed foil, while numerical simulation is required to investigate short wavelength mode. A 2-D numerical model based on Lagrangian compressible fluid equations has been applied to study evolution of the perturbation. The final amplitude's dependence on dimensionless parameters has been considered. This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC03-92SF19460, the University of Rochester, and the New York State Energy Research and Development Authority.

# Numerical Study of Feed-out of Short-Wavelength Rear-Surface Perturbations in Planar Targets

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# Abstract

The propagation of a small, short-wavelength perturbation from the back to the front surface of a laser-accelerated planar foil is investigated numerically, the foil being considered as an ideal gas. The front surface is initially flat, while the back surface is rippled. After the initial shock reaches the back surface, the rippled, reflected rarefaction wave propagates toward the front and thus transfers the perturbation from the back surface to the front surface. Once the front becomes rippled, the Raleigh–Taylor instability is seeded and the perturbation grows exponentially in time. An approximate solution of linearized compressible flow equations can be found when the ripple wavelength is longer than the thickness of the compressed foil, while numerical simulation is required to investigate the short-wavelength mode. A 2-D numerical model based on Lagrangian compressible fluid equations has been applied to study evolution of the perturbation. The final amplitude's dependences on dimensionless parameters has been considered.

# What do we want to do?

- Distortion of the front surface is assumed to be given by

$$\Delta_{fs}(t) = F \cdot \Delta_0 \cdot e^{\gamma(t-t_{rb})}$$

Front-surface
distortion

Amplification
factor

Back-surface
initial nonuniformity

**$F = F(kd_{ps})$ is to be determined.**

k:  wave number

$d_{ps}$:  compressed target thickness

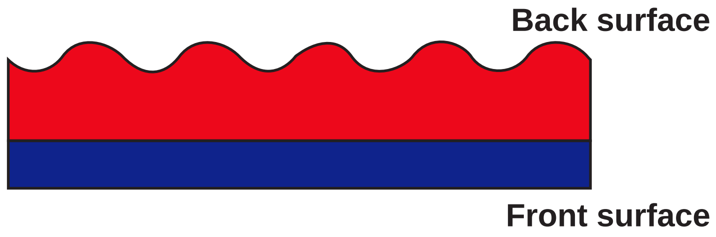
$t_{rb}$:  rarefaction break-out time

# Introduction

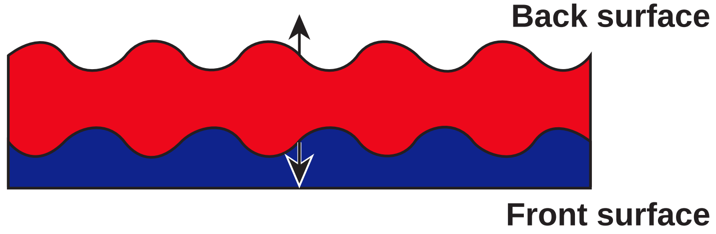
- The Rayleigh–Taylor instability in targets accelerated by a laser can be seeded by the nonuniformities of both the front and back surfaces of the target. Even if the front surface is initially flat, perturbations from the back surface propagate through the target and reach the ablation front seeding its RT instability.

- In this work we describe the feed-out of single-mode small perturbations in laser-accelerated planar targets.

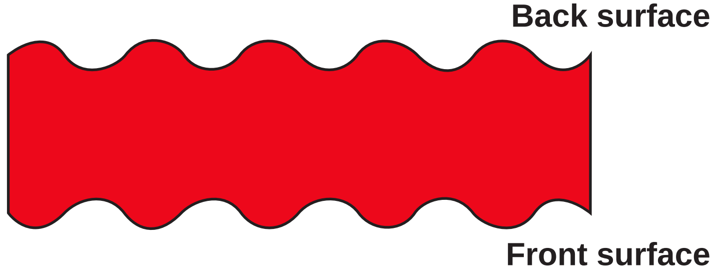
1. Flat shock



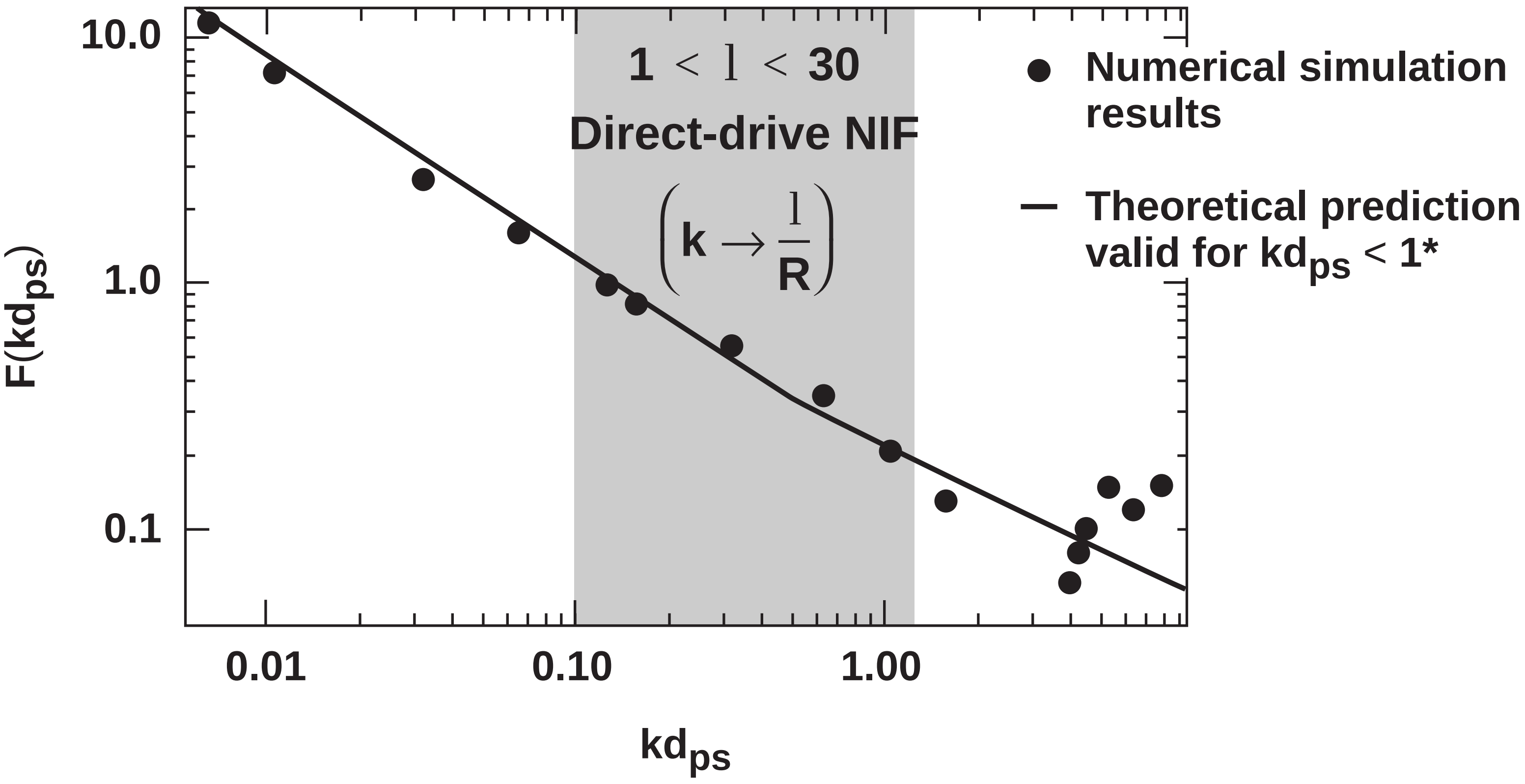
2. Perturbed rarefaction



3. Imprinting the perturbation



# Theory developed for long-wavelength perturbation is confirmed by simulations



- Need for ablative case for short-wavelength ($kd_{ps} > 1$) perturbation

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*R. Betti *et al*., PRL, 81 (25), 5560 (1998).

# Gas-dynamic model used in the computations

**Mass conservation:** $\frac{\partial \rho}{\partial \mathbf{t}} + \nabla \cdot (\rho \underline{\mathbf{u}}) = \mathbf{0}$

**Momentum:** $\frac{\partial \underline{\mathbf{u}}}{\partial \mathbf{t}} + \underline{\mathbf{u}} \cdot \nabla \underline{\mathbf{u}} = -\frac{\mathbf{1}}{\rho} \nabla \mathbf{P}$

**Energy:** $\rho \mathbf{c}_{\nu} \left( \frac{\partial \mathbf{T}}{\partial \mathbf{t}} + \underline{\mathbf{u}} \cdot \nabla \mathbf{T} \right) = \nabla \cdot \kappa \nabla \mathbf{T} - \mathbf{P} (\nabla \cdot \underline{\mathbf{u}}) + \mathbf{S}$

**Equation of state:** $\mathbf{P} = \mathbf{P}(\rho, \mathbf{T})$

**where** $\rho$: **density** | **P: pressure** | **T: temperature**

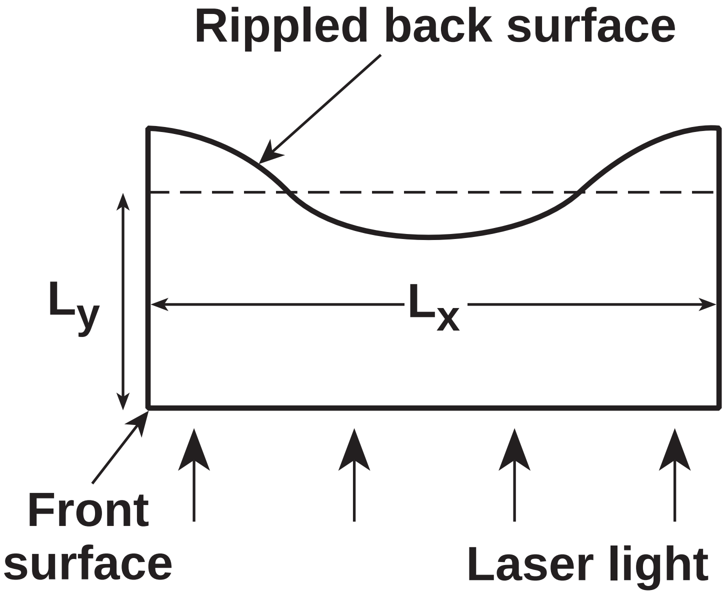
**u: velocity** | $\kappa$: **conductivity** | **S: heat source**

$\mathbf{c}_{\nu}$: **specific heat at constant volume**

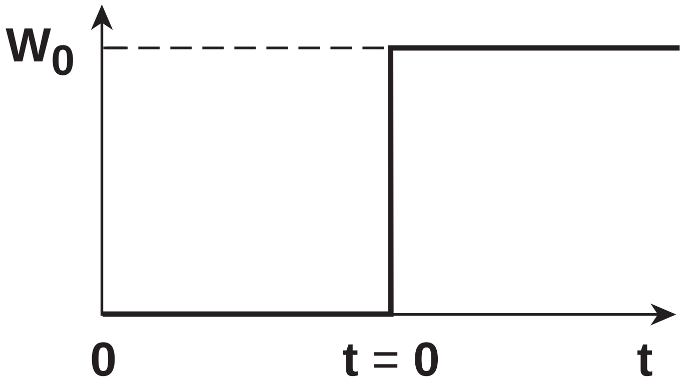
**K ~** $\mathbf{T}^{\nu}$: $\nu$ **= 1 for CH target,** $\nu$ **= 5/2 for DT target**

# We consider a flat foil irradiated by laser light; the rear surface is initially rippled

Geometry at t = 0

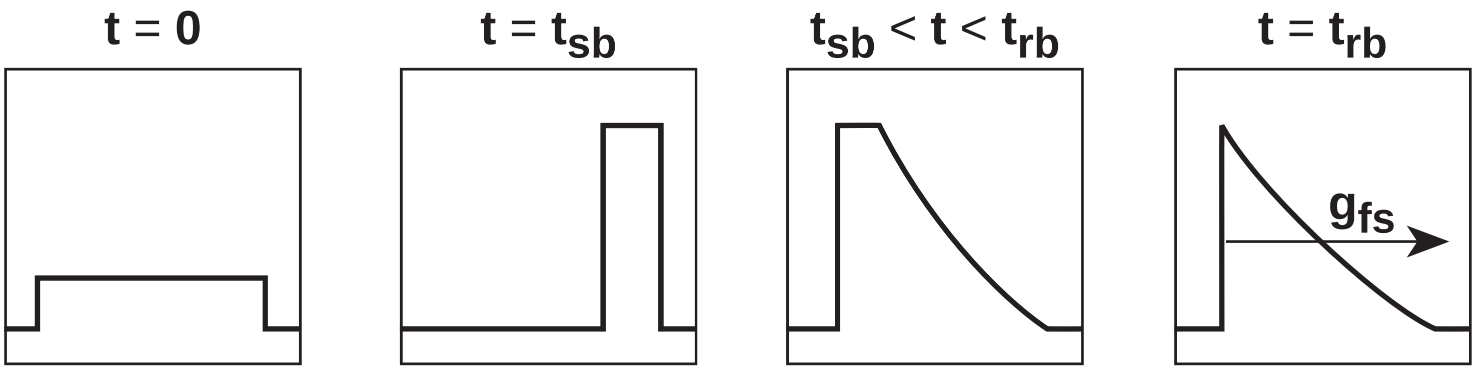


Laser pulse profile



# One-dimensional density profiles of ICF targets evolve through 4 stages

## Evolution of 1-D density distribution

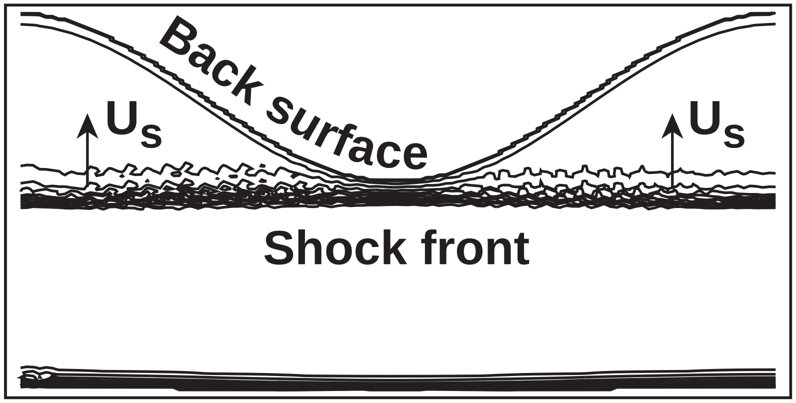


$t_{sb}$: shock breakout time

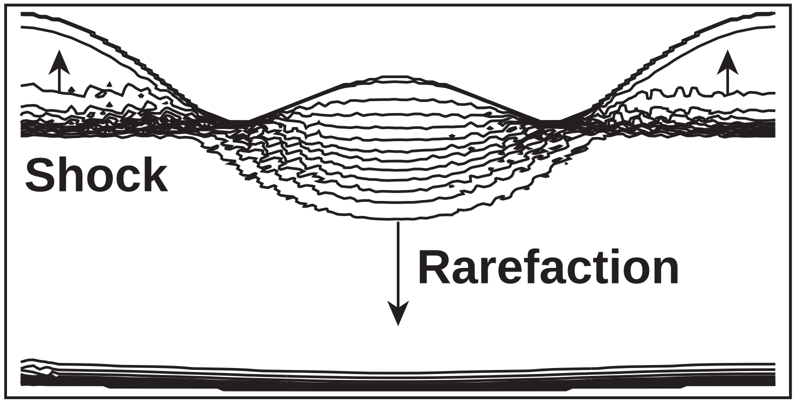
$t_{rb}$: rarefaction breakout time

# Two-dimensional qualitative behavior in the presence of a rippled rear surface

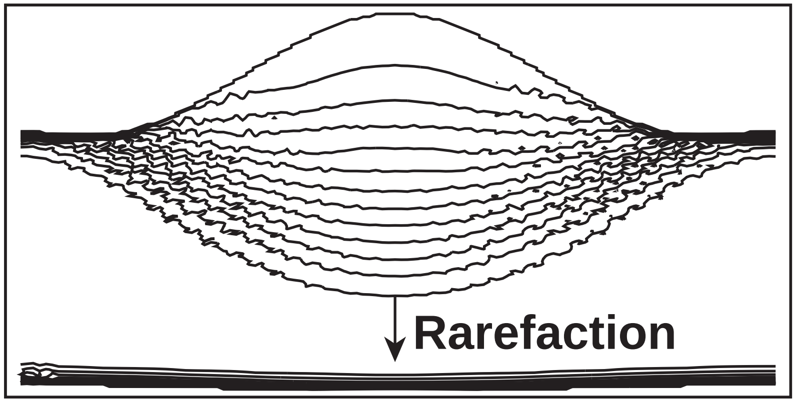
(a) The shock reaches the rippled rear surface.



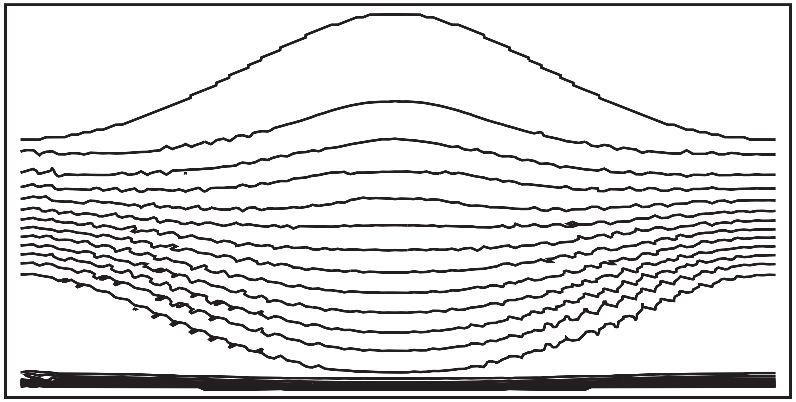
(b) Shock and rippled surface interact.



(c) The rippled rarefaction front is formed.

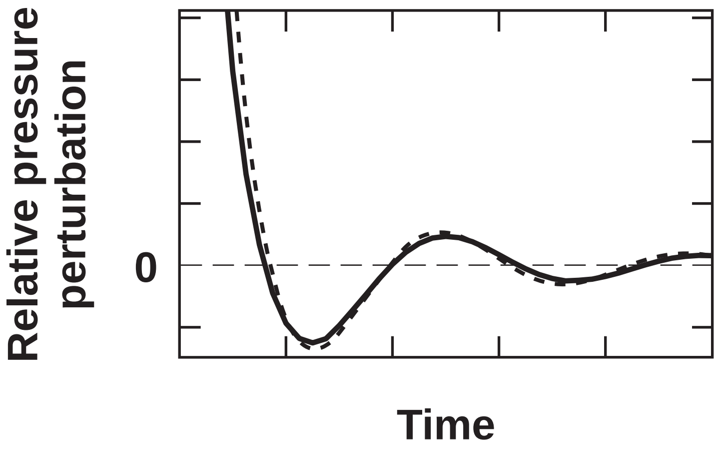


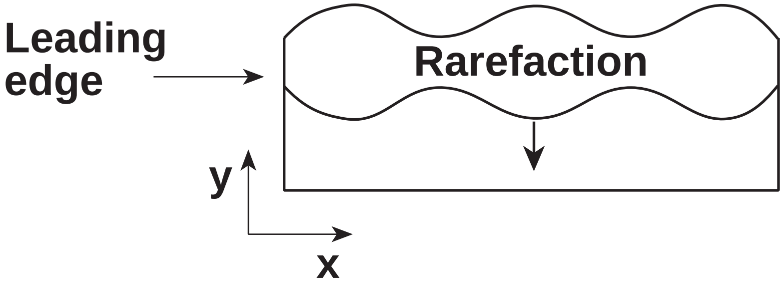
(d) The rarefaction reaches the front surface.



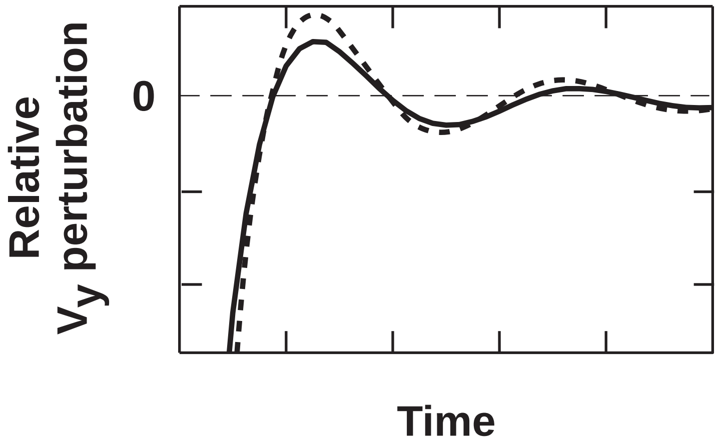
# Temporal evolution of small perturbations in a rarefaction wave

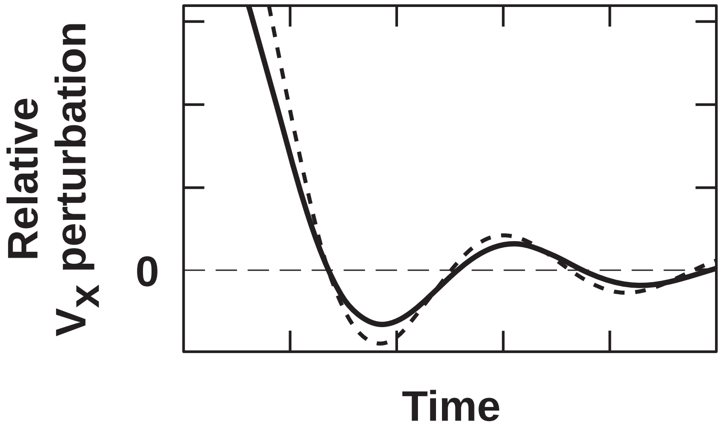
- - - Theory* —— Simulation





- At the leading edge perturbations oscillate in time.





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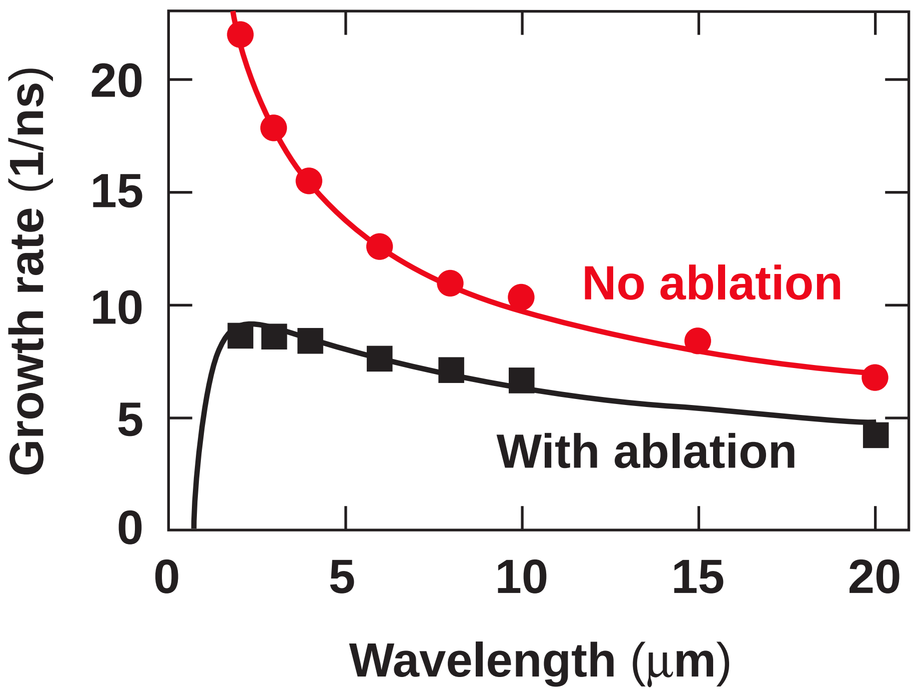
*A. Velikovich and L. Phillips, Phys. Fluids. 8 (4), 1107 (1996).

# Short-wavelength feed-out growth rates are in agreement with theoretical predictions*

- As expected, the seeded ablation surface perturbation grows according to ablative RT theory.
- Ablation significantly reduces short-wavelength-mode growth rate.
- 20-µm CH target
- Laser intensity = 120 TW/cm$^2$
- Acceleration = 150 µm/ns$^2$
- Ablation velocity = 1.25 µm/ns



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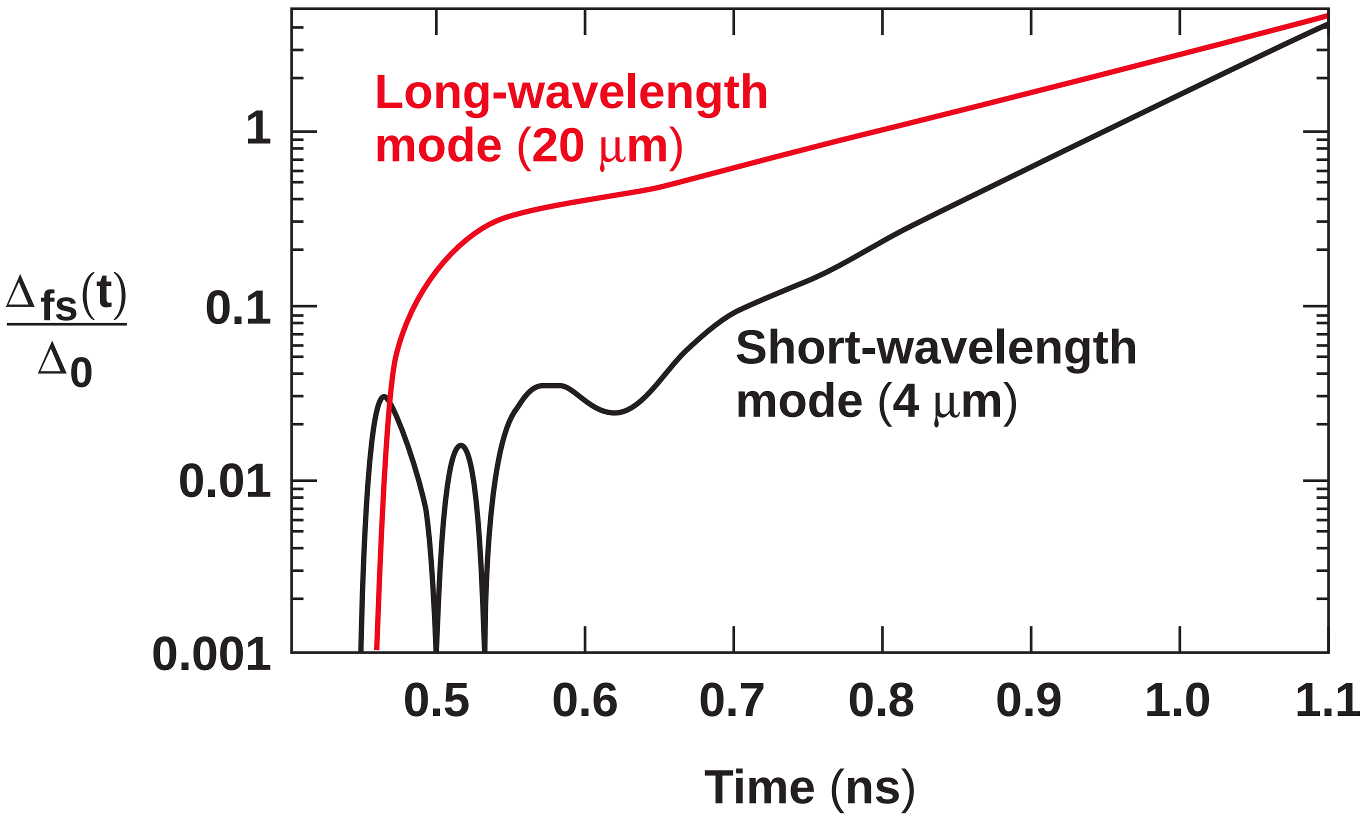
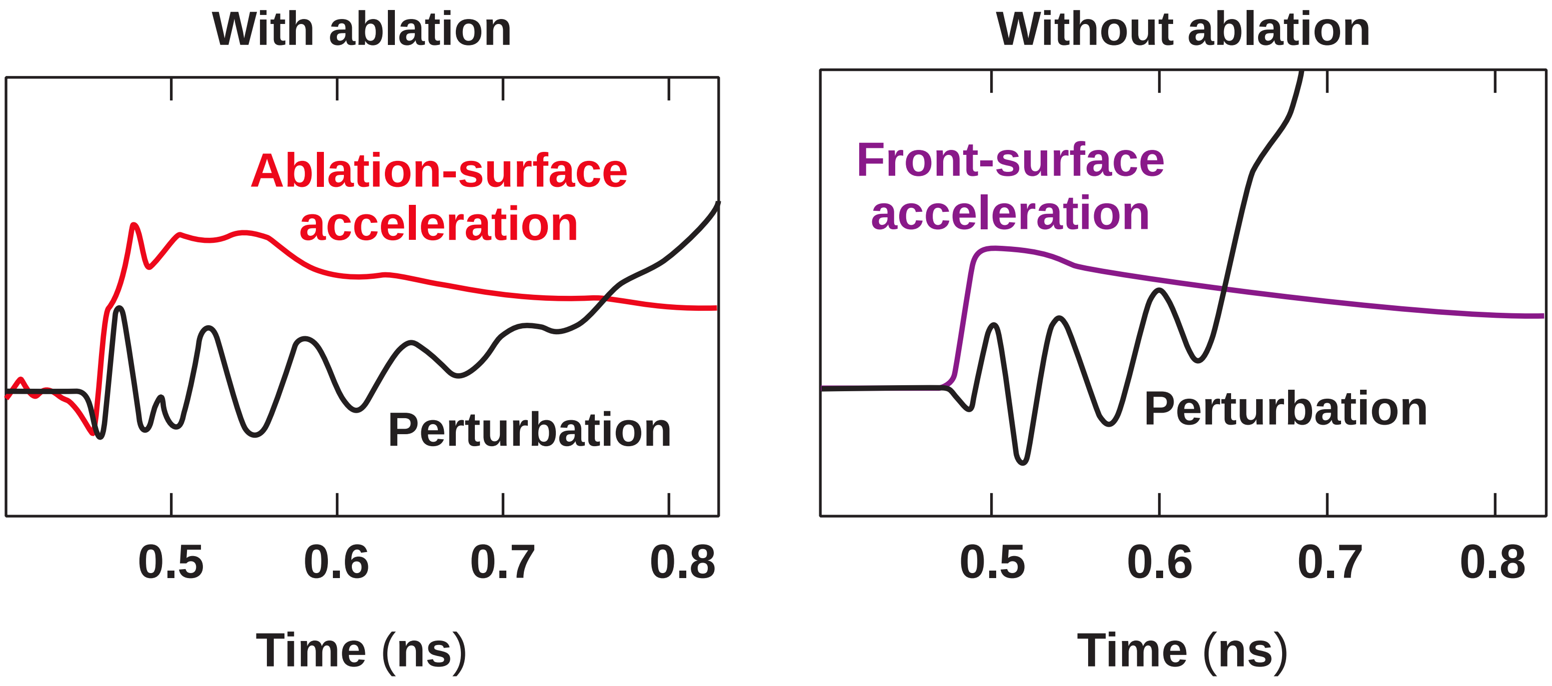
*R. Betti, Phys. Plas. 5, 1446 (1998).

# Short-wavelength modes oscillate, while long-wavelength modes do not



# With or without ablation, the seeded front-surface perturbations have qualitatively similar behavior

- Both with and without ablation, the short-wavelength mode oscillates and then grows exponentially.



# The amplitude of short-wavelength perturbations is significantly reduced by mass ablation

- **Amplification factor F($kd_{ps}$):**

  $\Delta_{fs}(t) = F\Delta_0 e^{\gamma(t-t_{rb})}$

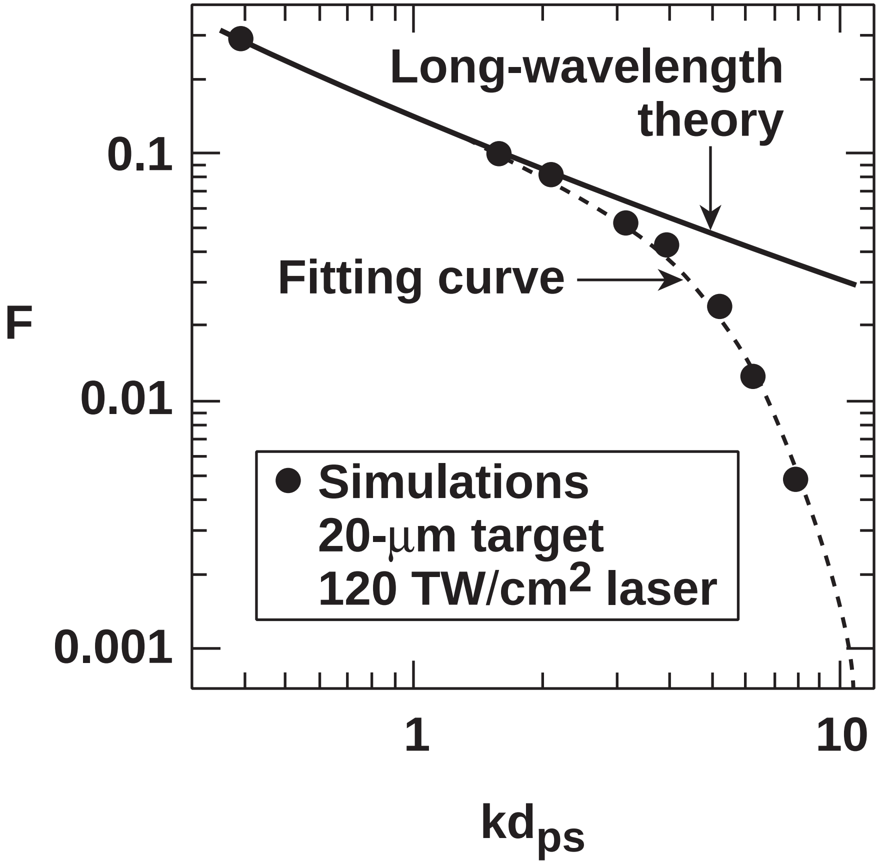
  $\Delta_{fs}(t)$: **front-surface perturbation**

  $\Delta_0$: **initial back-surface perturbation**

  $d_{ps}$: **thickness of compressed target**

  $t_{rb}$: **rarefaction break-out time**

- **Fitting**
  $\log(F) = \log(F_B)[1 + \alpha(kd_{ps})^2]$

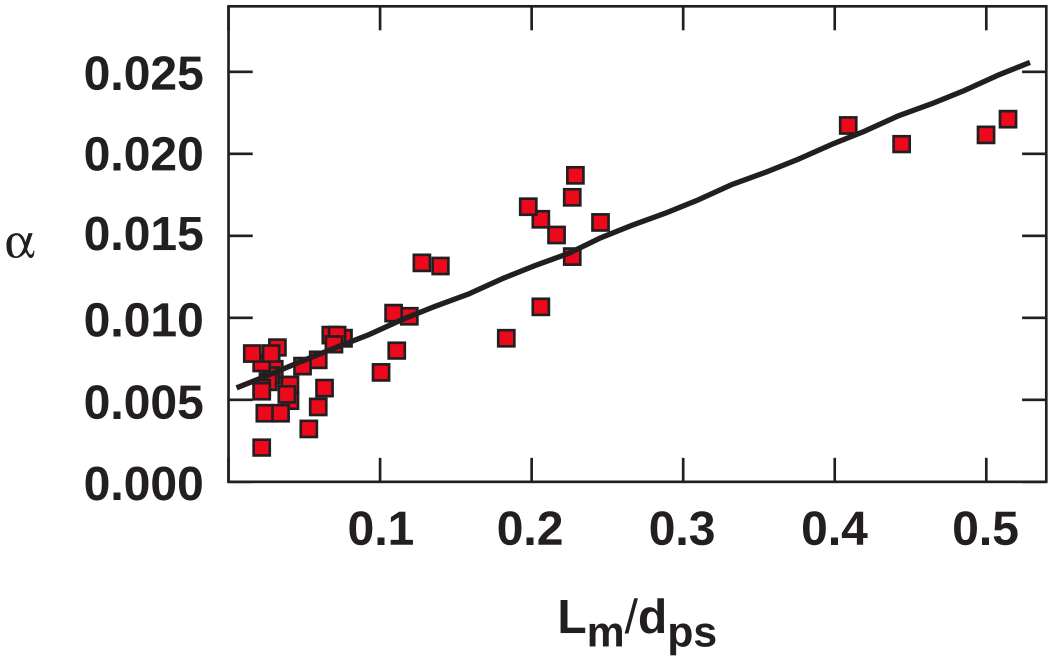


# Numerous simulations have been performed to investigate the factor $\alpha$

- **Parameters of materials have been chosen close to that of the CH target.**
- **Laser intensity is in the range of 10 to 120 TW/cm$^2$, the foil thickness is 20 $\mu$m.**
- **The amplification factor depends on dimensionless parameters of the problem.**
- **The dimensionless parameter $L_m/d_{ps}$, where $L_m = \min[\rho(d\rho/dx)^{-1}]$, has been chosen to be considered.**

# The reduction of the amplification factor depends on the ablation-front thickness

- **The data are fitted by the linear law $\alpha = a + b\,L_m/d_{ps}$, where $a = 0.005$, $b = 0.038$**



$$\mathrm{Log}(F) = \mathrm{Log}(F_B)\,[1 + \alpha(kd_{ps})^2]$$

$$= \mathrm{Log}(F_B)\,[1 + 0.005\,(kd_{ps})^2 + 0.038\,(kL_m)(kd_{ps})],$$

$$\text{where } F_B = \frac{1}{16}\left(\frac{1}{kd_{ps}} + \frac{1.25}{\sqrt{kd_{ps}}}\right).$$