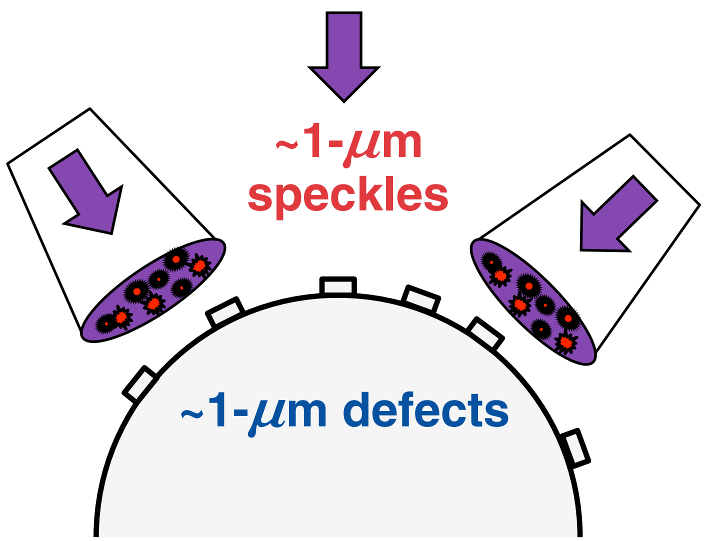
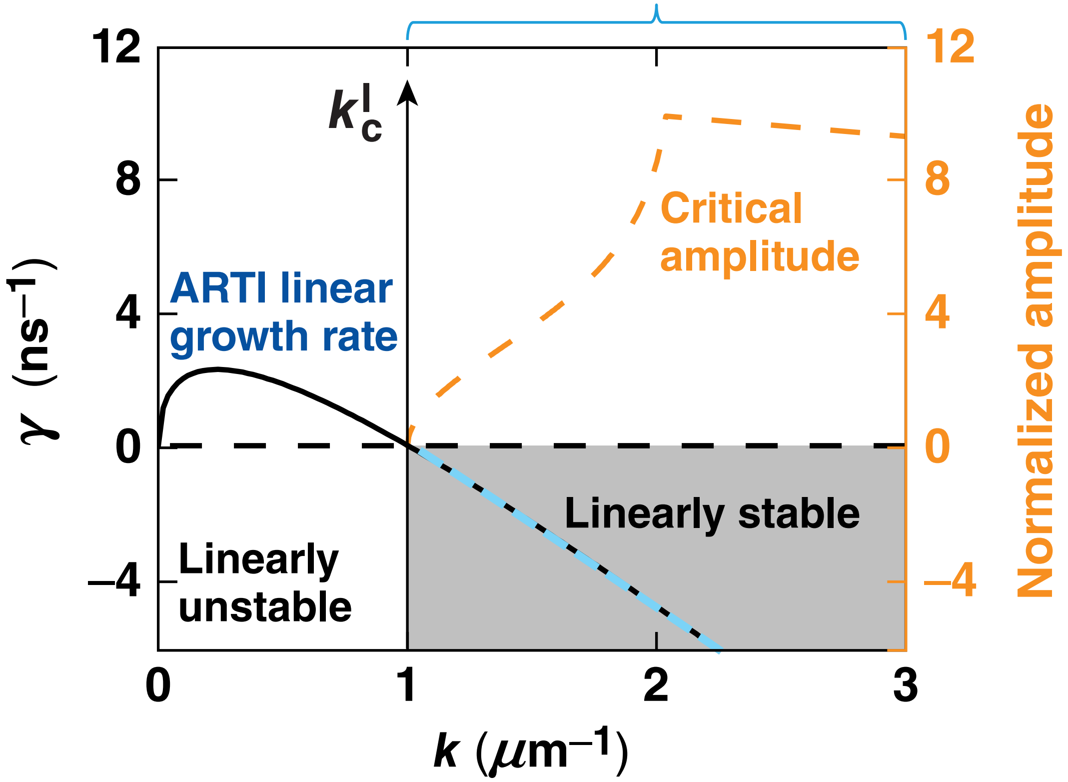
Nonlinear Excitation of the Linearly Stable Ablative Rayleigh–Taylor Instability for All Wave Numbers





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Summary

All of the ablative Rayleigh–Taylor instability (ARTI) modes beyond the linear and the nonlinear cutoff can be destabilized by a finite-amplitude perturbation

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- The nonlinear excitation of the single-mode ARTI is investigated by numerical simulations in both 2-D and 3-D
  - in inertial confinement fusion (ICF), the micro-sized finite-amplitude perturbations can be induced by target defects and laser imprinting
  - all linearly stable ablative Rayleigh–Taylor (ART) modes can be nonlinearly destabilized by finite-amplitude perturbation
  - linearly stable ARTI is more easily destabilized in 3-D than in 2-D, and saturates at higher bubble velocity and bubble density
  - small-scale 3-D modes are more efficient at driving mix than 2-D modes in ICF implosions

TC13710

Collaborators

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Finite-amplitude perturbations can nonlinearly destabilize the linearly stable modes

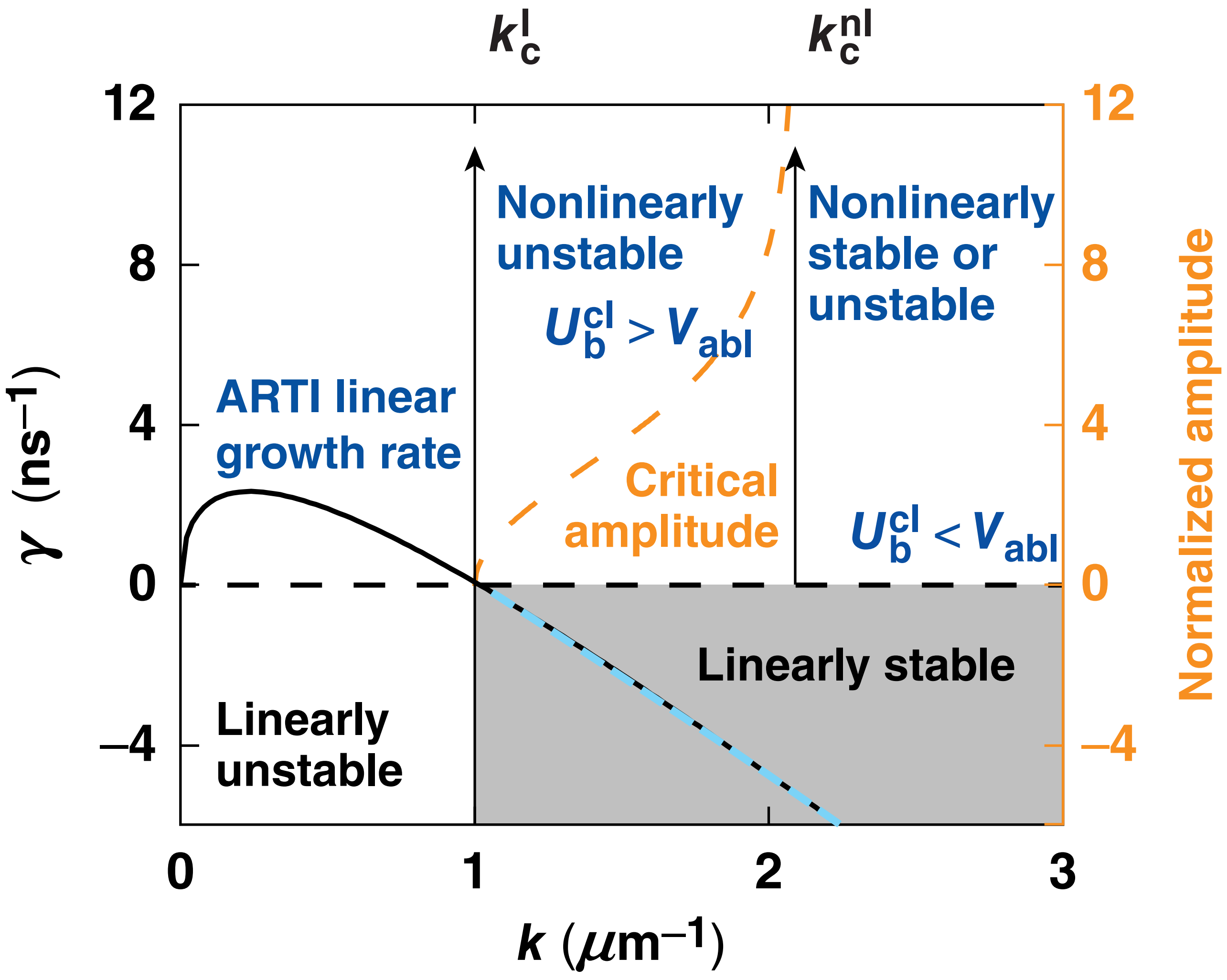
Nonlinear ARTI theory* for low rotational flow ($V_{rot} \ll V_a$):

$$U_b^{ART} = U_b^{cl} = \sqrt{g(1-r_d)/C_g k}$$

$$r_d = \rho_1/\rho_h,\ C_g = 3 \text{ for 2-D},\ C_g = 1 \text{ for 3-D}$$

Nonlinear cutoff:

$$U_b^{cl} = \sqrt{g(1-r_d)/C_g k_c^{nl}} = V_{abl}$$



*V. N. Goncharov, Phys. Rev. Lett. 88, 134502 (2002);
J. Sanz *et al.*, Plasma Phys. Control. Fusion 46, B367 (2004).

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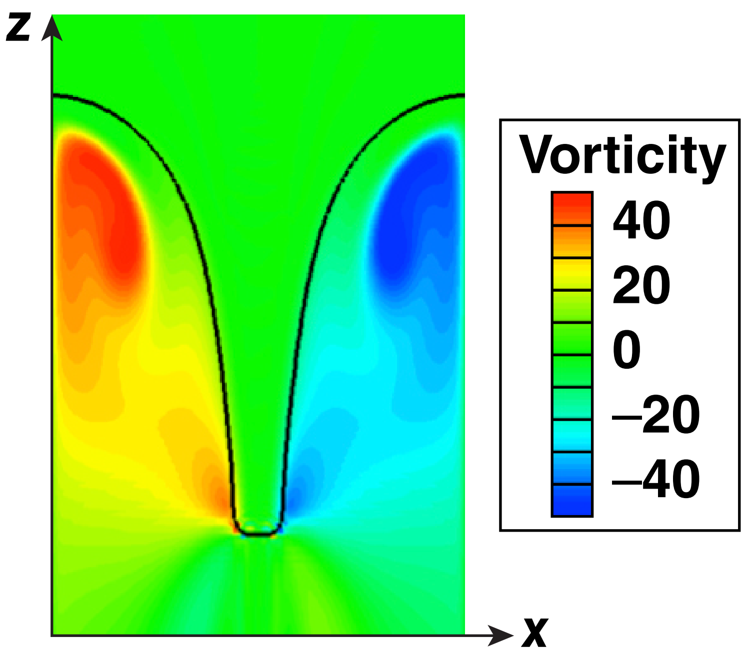
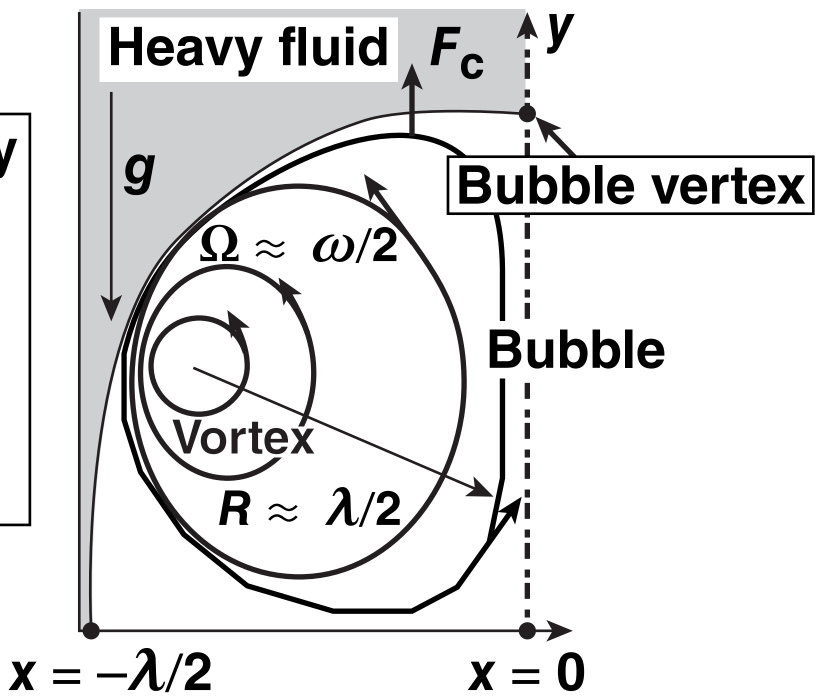
The small-scale bubble can be accelerated above the classical terminal bubble velocity by ablation-generated vorticity*





Centrifugal force: $\rho_b R\omega^2/4$

Vorticity scales as: $\omega = \eta(kV_{abl}/r_d) \quad \eta \sim 2 \quad r_d < 1$

Nonlinear terminal bubble velocity:* $U_b^{rot} = \sqrt{(U_b^{cl})^2 + \eta^2 V_{abl}^2/4r_d} > U_b^{cl}$

Rotational effects

* R. Betti and J. Sanz, Phys. Rev. Lett. 97, 205002 (2006); R. Yan *et al.*, Phys. Plasmas 23, 022701 (2016).

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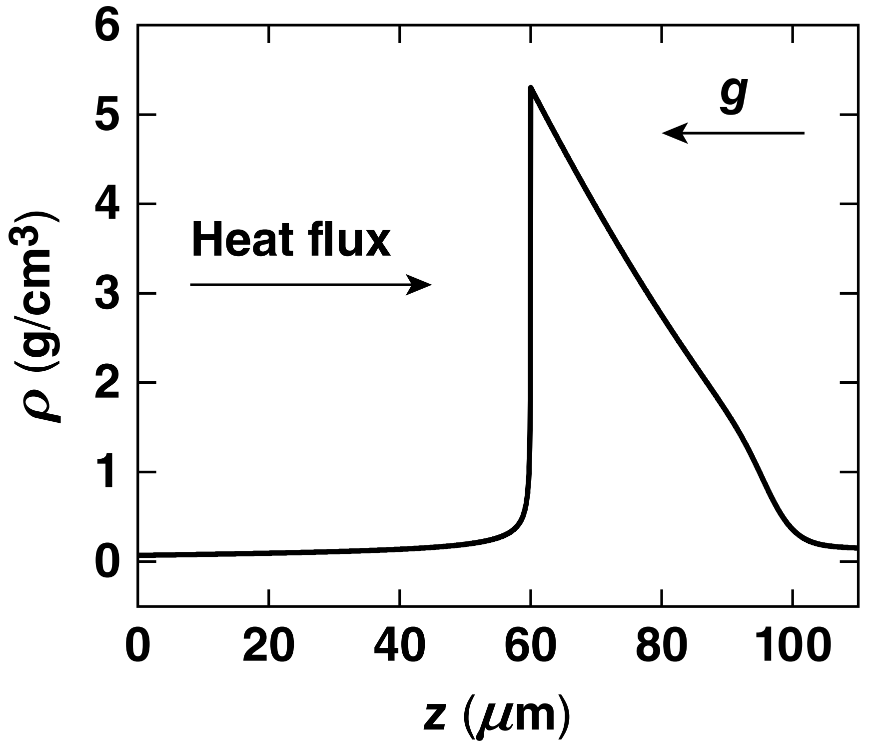
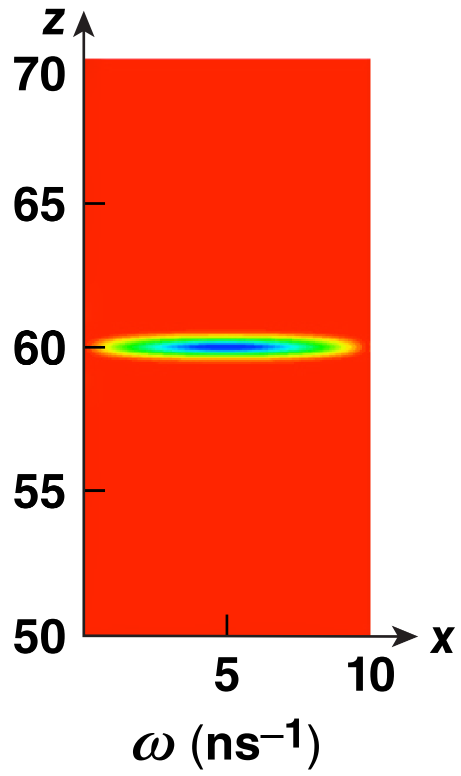
A controlled simulation is used to study the nonlinear excitation of a single ARTI mode

- A controlled planar simulation reproduces the typical acceleration phase of a direct-drive target
- The ARTI is seeded by velocity perturbation V_p

P_{abl} = 120 Mbar $g(t = 0)$ = 100 μm/ns^2 V_{abl} = 3.5 μm/ns



Initial vorticity



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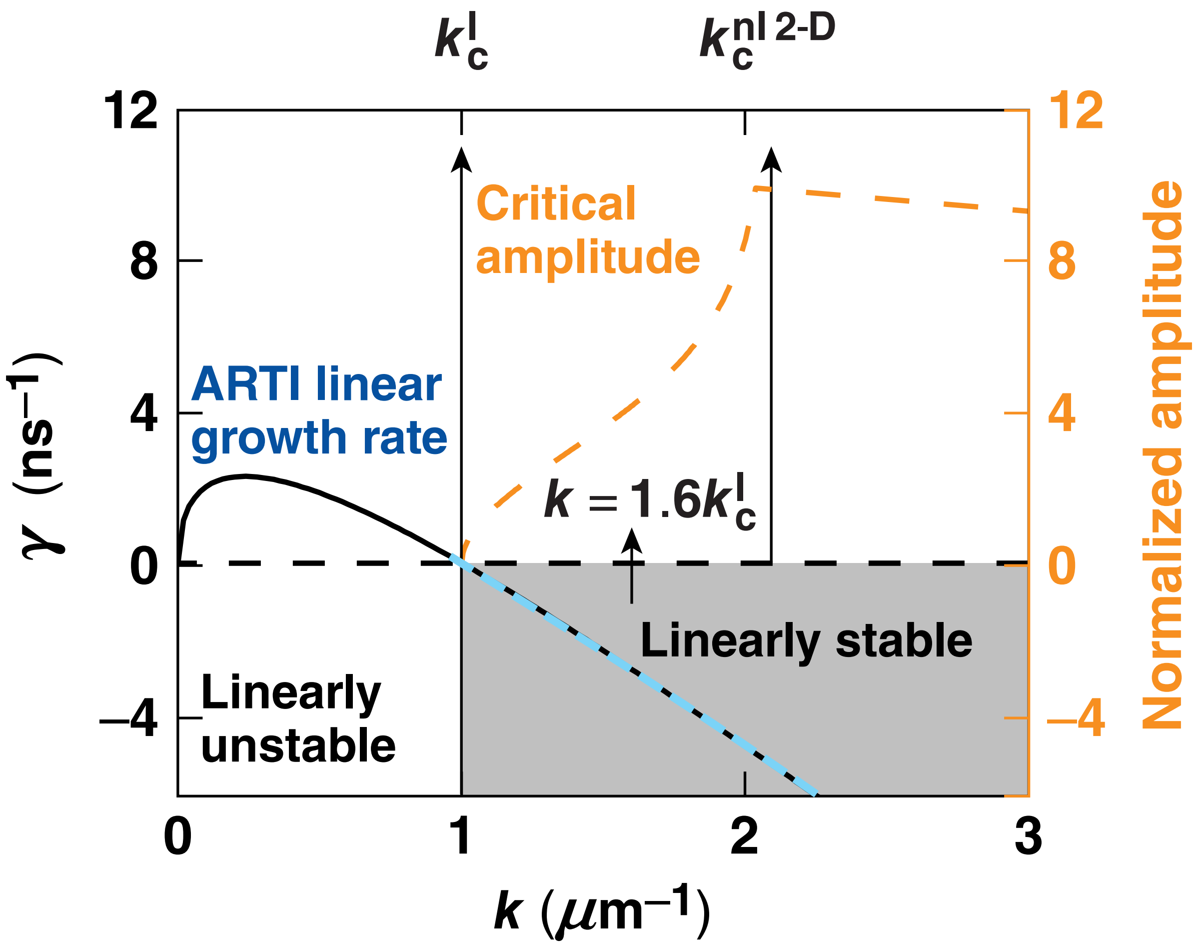
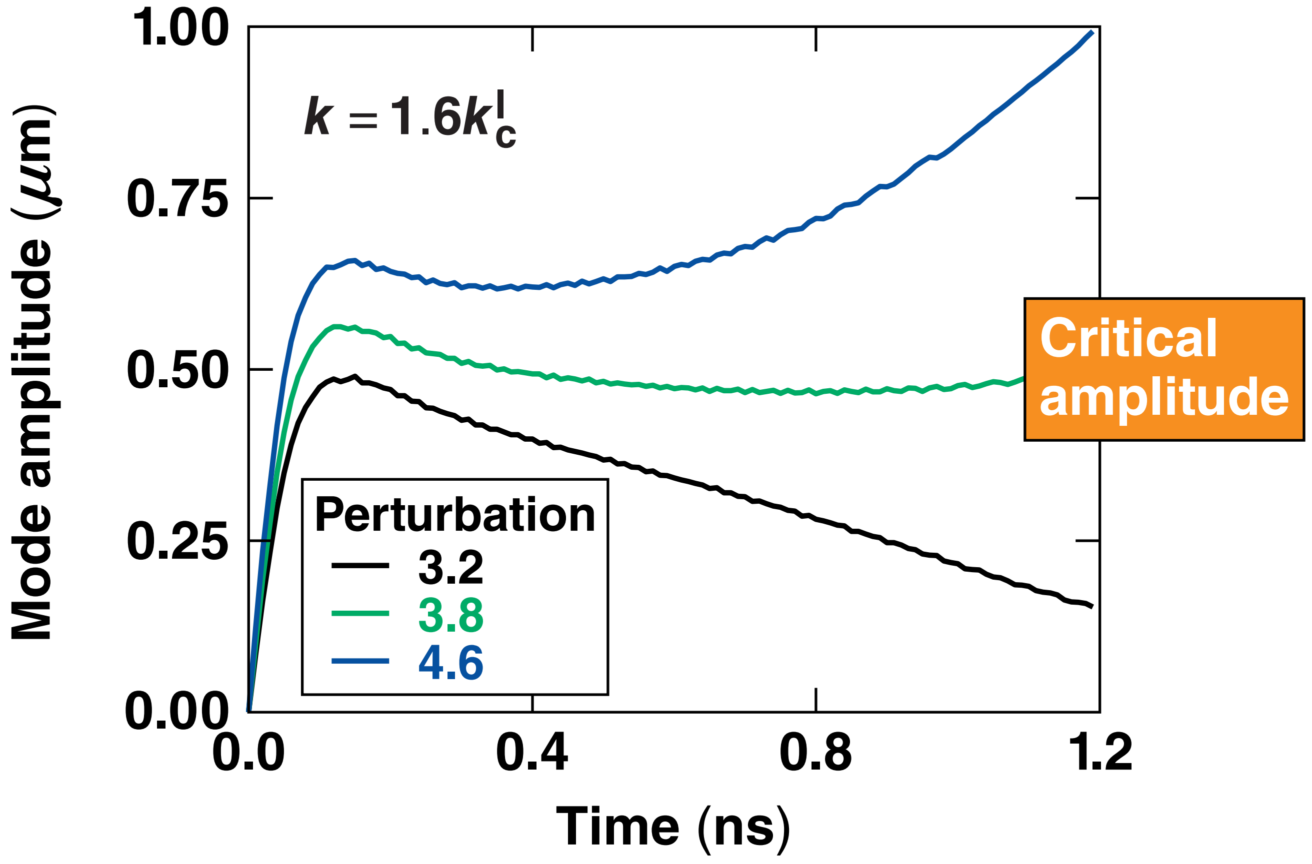
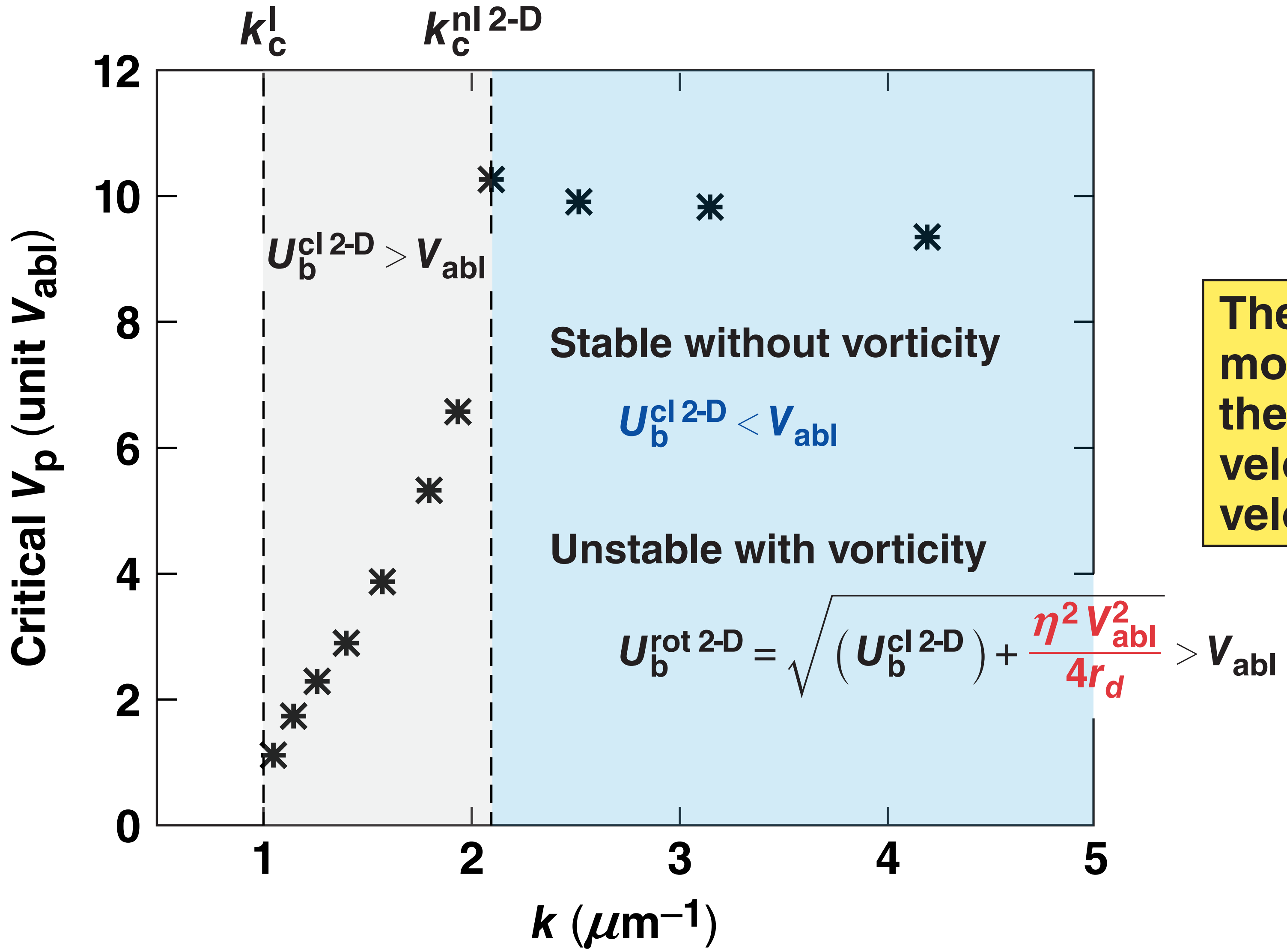
Linearly stable ARTI can be nonlinearly destabilized by a finite-amplitude perturbation





All modes beyond the linear cutoff can be destabilized for a sufficiently large perturbation

Vorticity dominates the new unstable region $(k > k_c^{nl})$



The destabilization of the ARTI modes beyond k_c^{nl} is a result of the enhancement of the bubble velocity above the ablation velocity by large vorticity.

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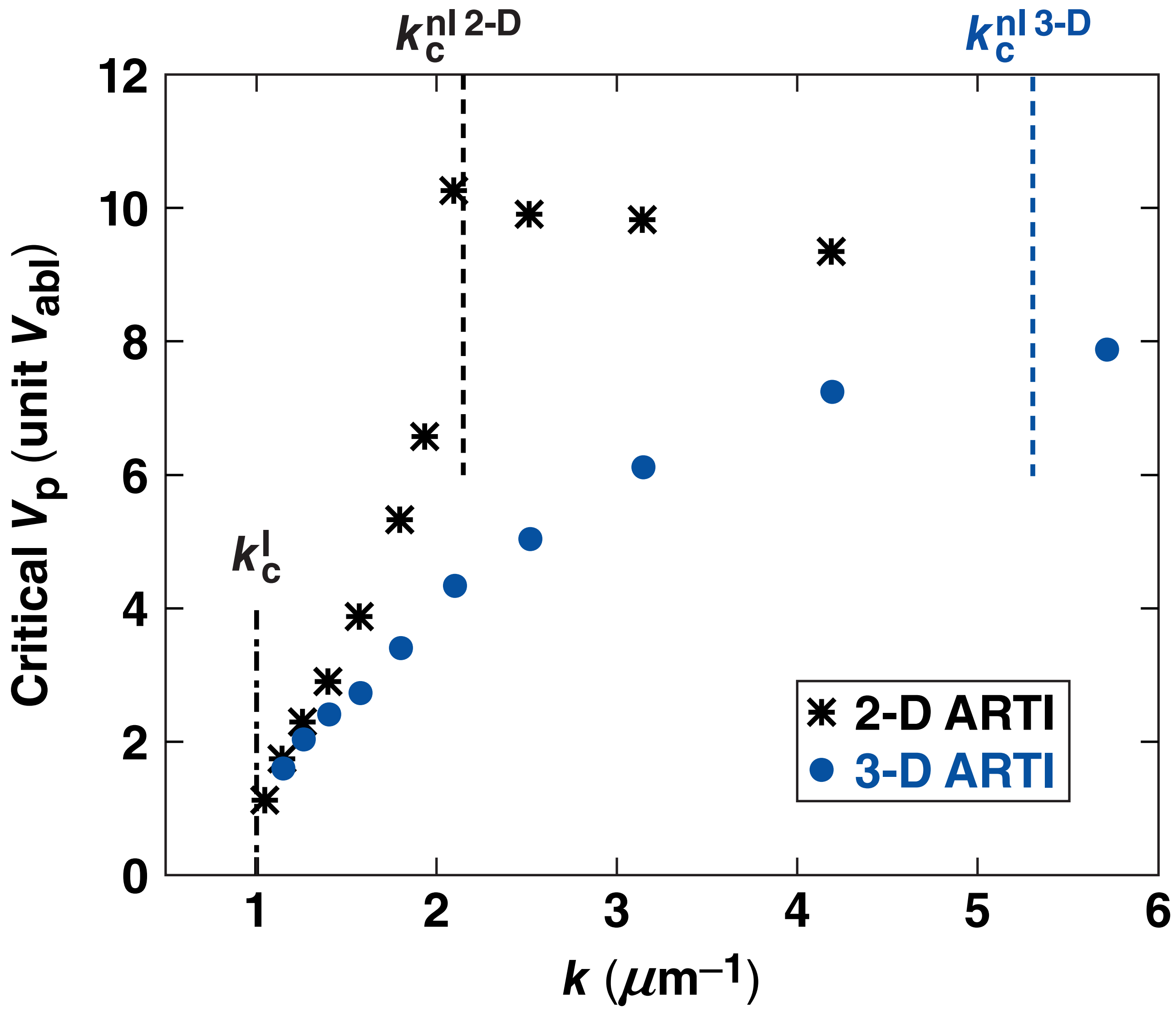
ARTI beyond the linear cutoff is more easily destabilized in 3-D than in 2-D for the same wave number



- The critical amplitude of the 3-D ARTI is smaller than in 2-D
- $V_p \sim 10\ V_{abl}$ (or 1.4-μm surface perturbation) for all modes

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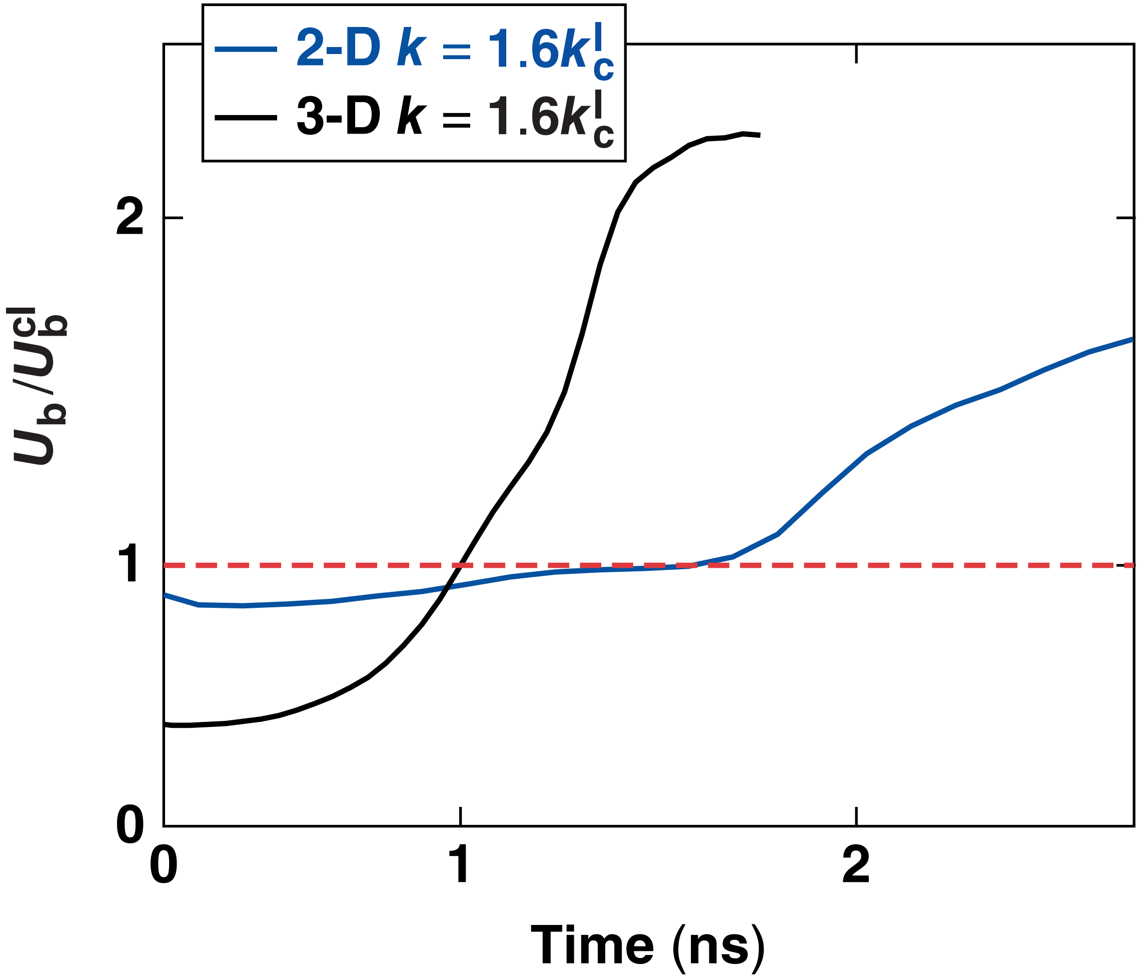
A 3-D bubble penetrates into the target much faster than in 2-D



- Consistent with the results for linearly unstable modes*

*R. Yan *et al.*, Phys. Plasmas 23, 022701 (2016).

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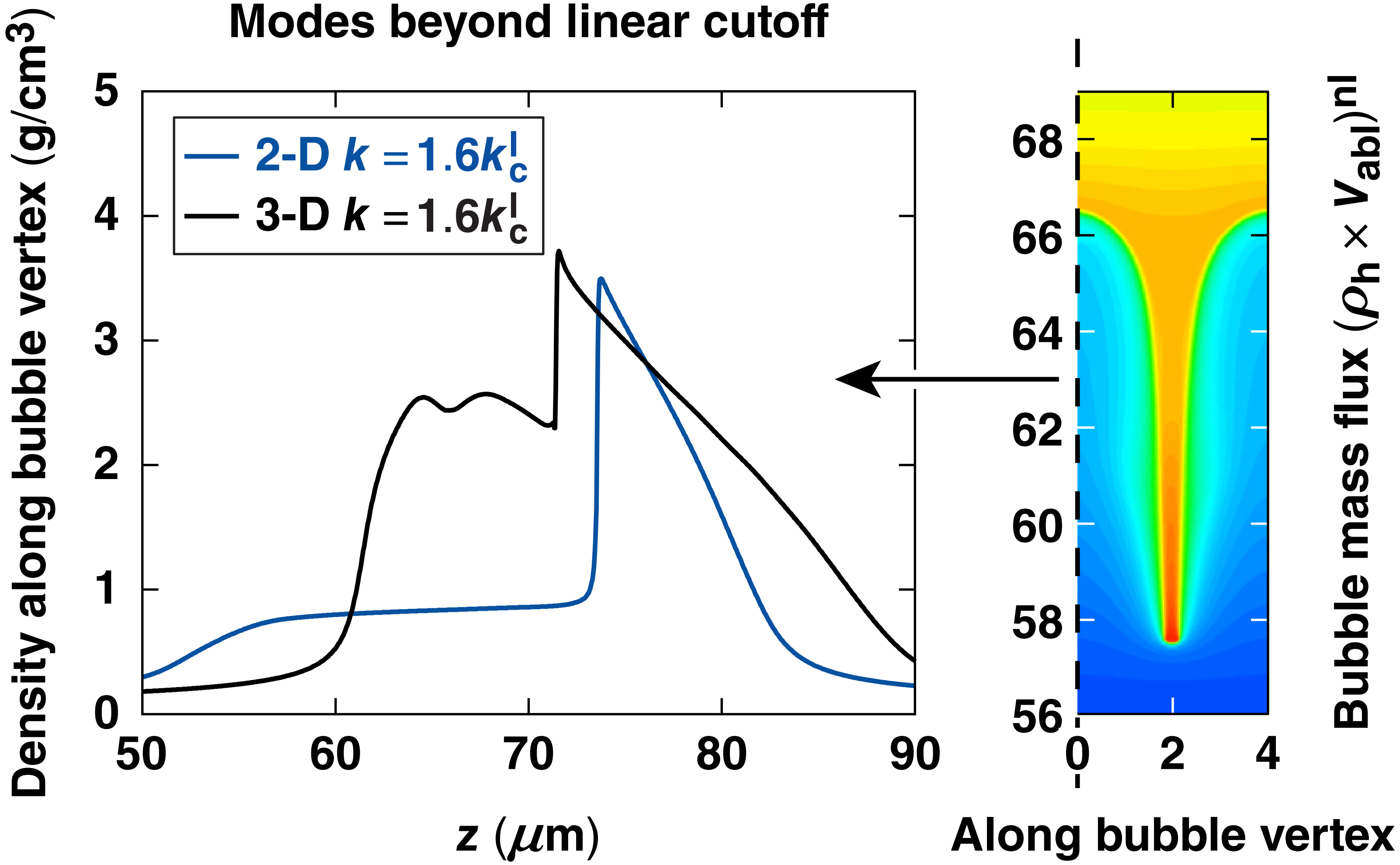
Small-scale 3-D modes are effective at driving mix in ICF implosions because of higher bubble density

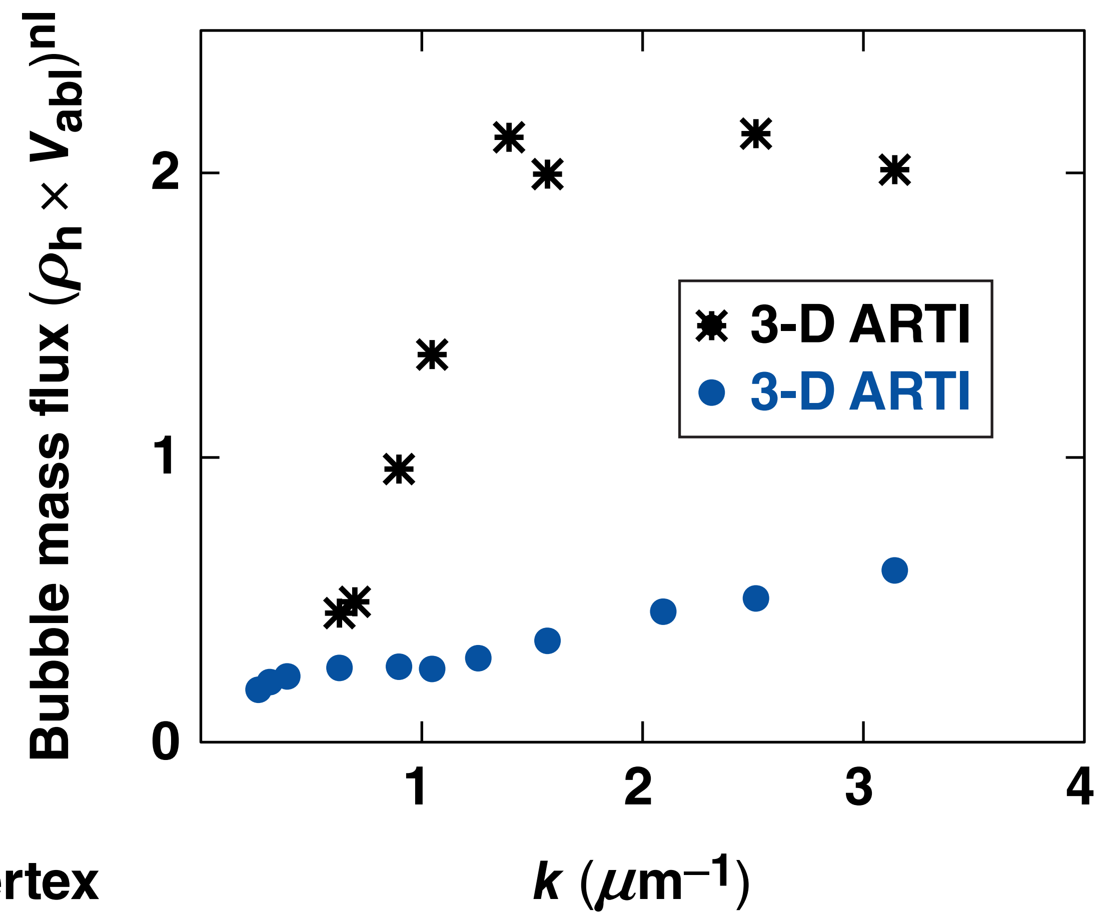
Higher bubble density in 3-D

Modes beyond linear cutoff



Higher mass flux in 3-D

Assess material mixing: $(\rho_b U_b)^{nl}$



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Summary/Conclusions

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