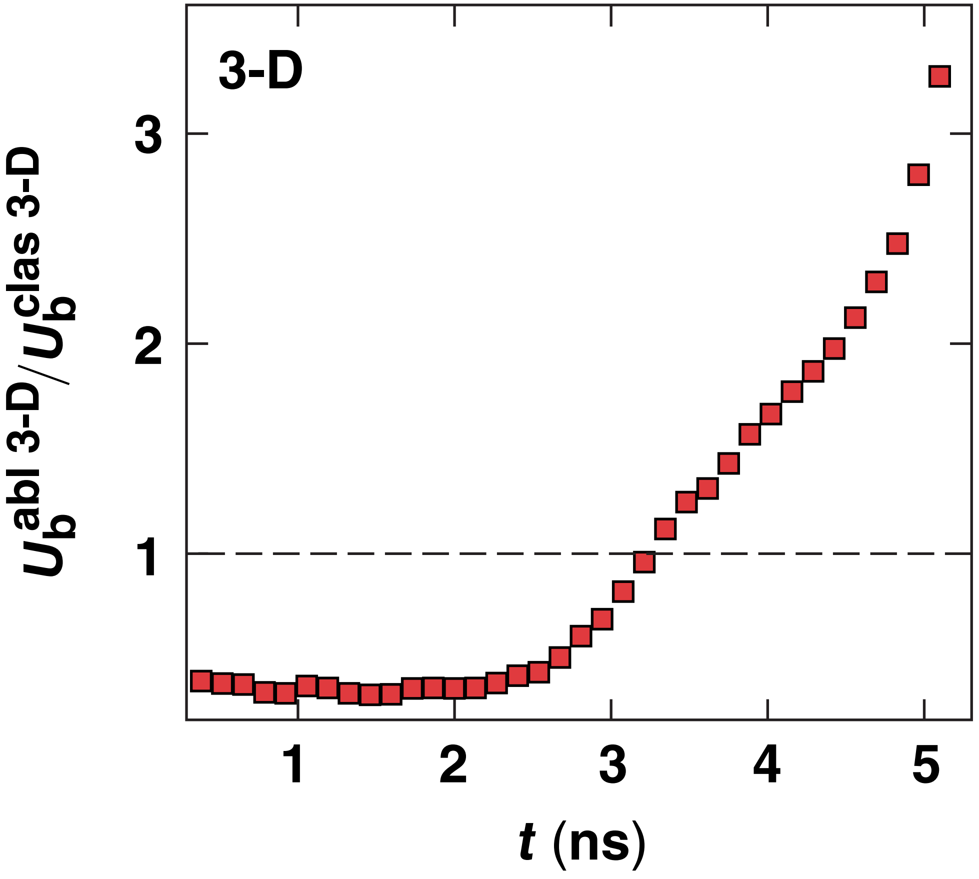
Three-Dimensional Single-Mode Nonlinear Ablative Rayleigh–Taylor Instability

3-D single-mode Rayleigh–Taylor bubble velocity for $\lambda = 10\ \mu$m



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Summary

Three-dimensional simulations show that the bubble growth in the ablative Rayleigh–Taylor instability (RTI) is faster than classical RTI predictions

- The single-mode bubble velocity in 3-D is faster than in 2-D
- No saturation is found for the 3-D ablative RTI bubble velocity, while the 2-D bubble velocity saturates above the classical value
- Vorticity accumulation inside the bubble caused by mass ablation accelerates the bubble to velocities well above the classical value

R. Yan *et al*., "Three-Dimensional Single-Mode Nonlinear Ablative Rayleigh–Taylor Instability," submitted to Physics of Plasmas.

Collaborators

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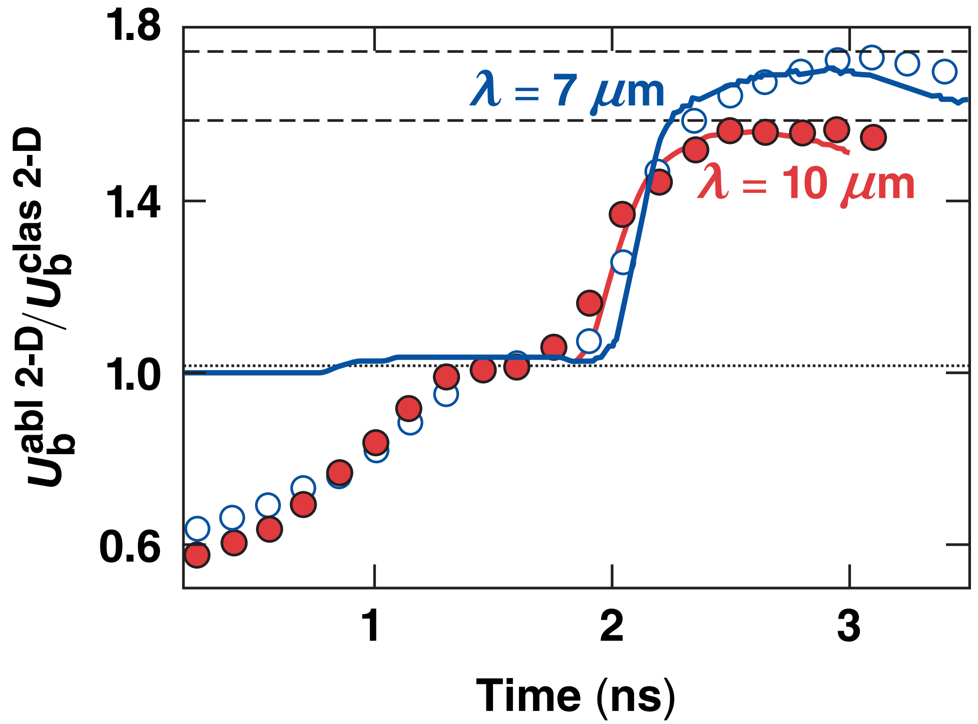
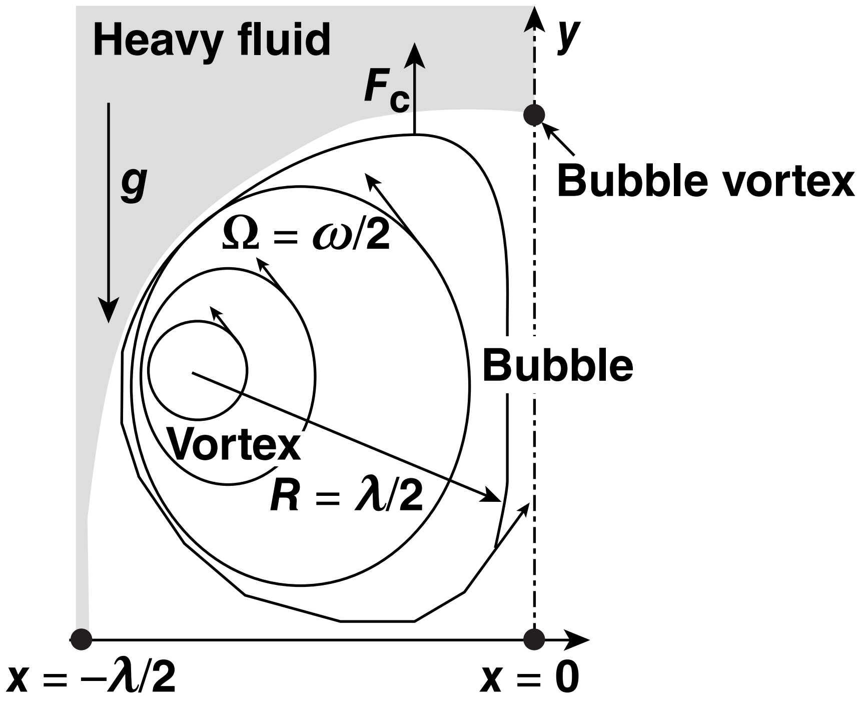
Ablation can stabilize RTI in the linear regime but can also cause RTI to grow faster in the nonlinear regime

Linear: Ablative Rayleigh–Taylor (RT) growth rate* $\gamma_{DT} = 0.94\sqrt{kg} - 2.7\,kV_{abl}$ (Stabilizing)

Nonlinear:





In the ablative RTI, the acceleration beyond classical is caused by a vortex inside the bubble.**

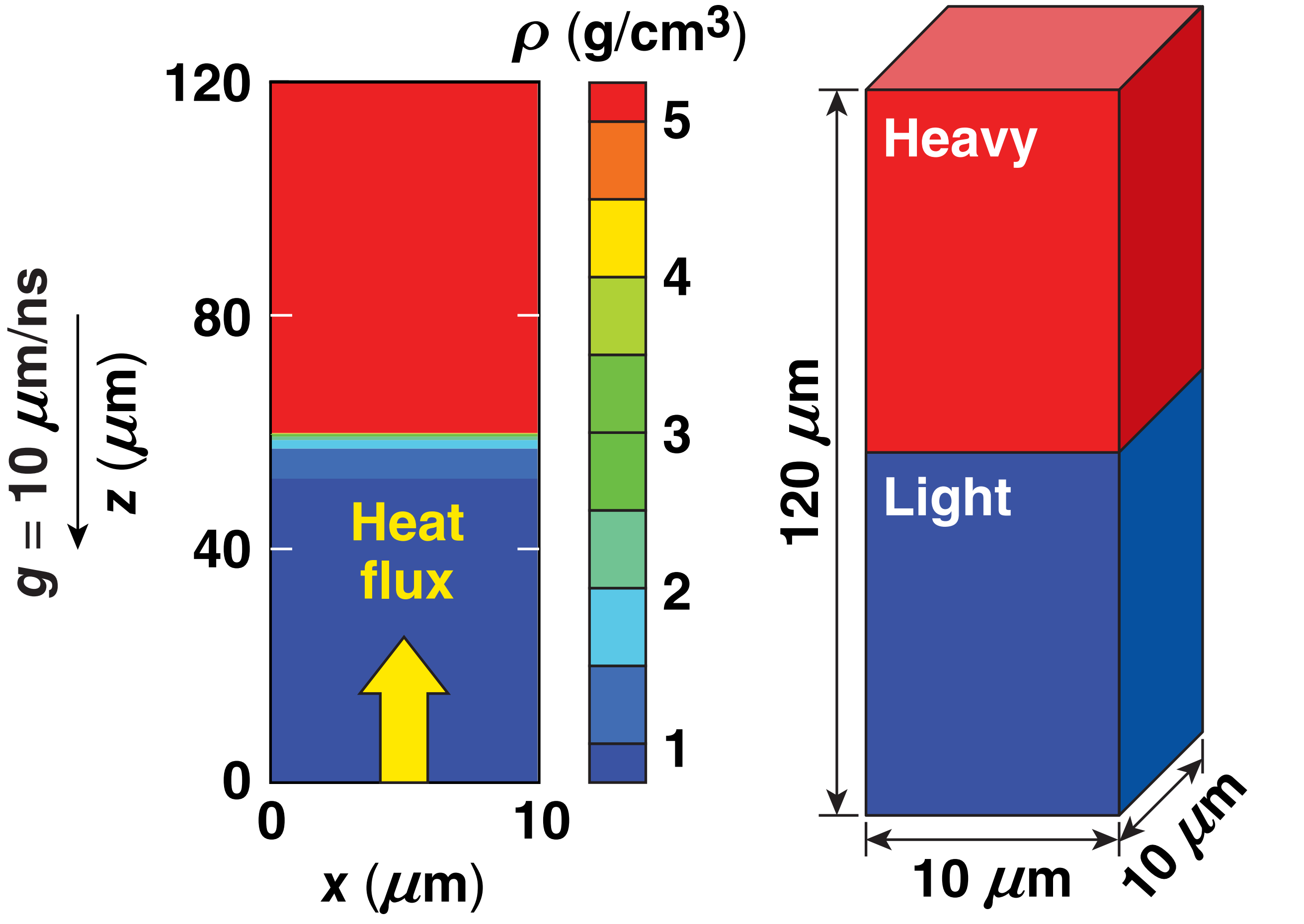
* R. Betti *et al.*, Phys. Rev. E 50, 3968 (1994).
** R. Betti and J. Sanz, Phys. Rev. Lett. 97, 205002 (2006).

TC12408

The *ART3D** simulations start from a quasi-equilibrium state relevant to a National Ignition Facility (NIF) target design

- The code *ART** has been parallelized and extended to 3-D geometry (*ART3D*)
- *ART3D* solves the single-fluid equations of motion including Spitzer thermal conduction over a Cartesian grid
- The gravity is dynamically adjusted to keep the interface quasi-stationary

Perturbations
2-D: ~cos(*kx*)
3-D: ~0.5 × [cos(*kx*) + cos(*ky*)]



V_{abl} = 3.5 μm/ns

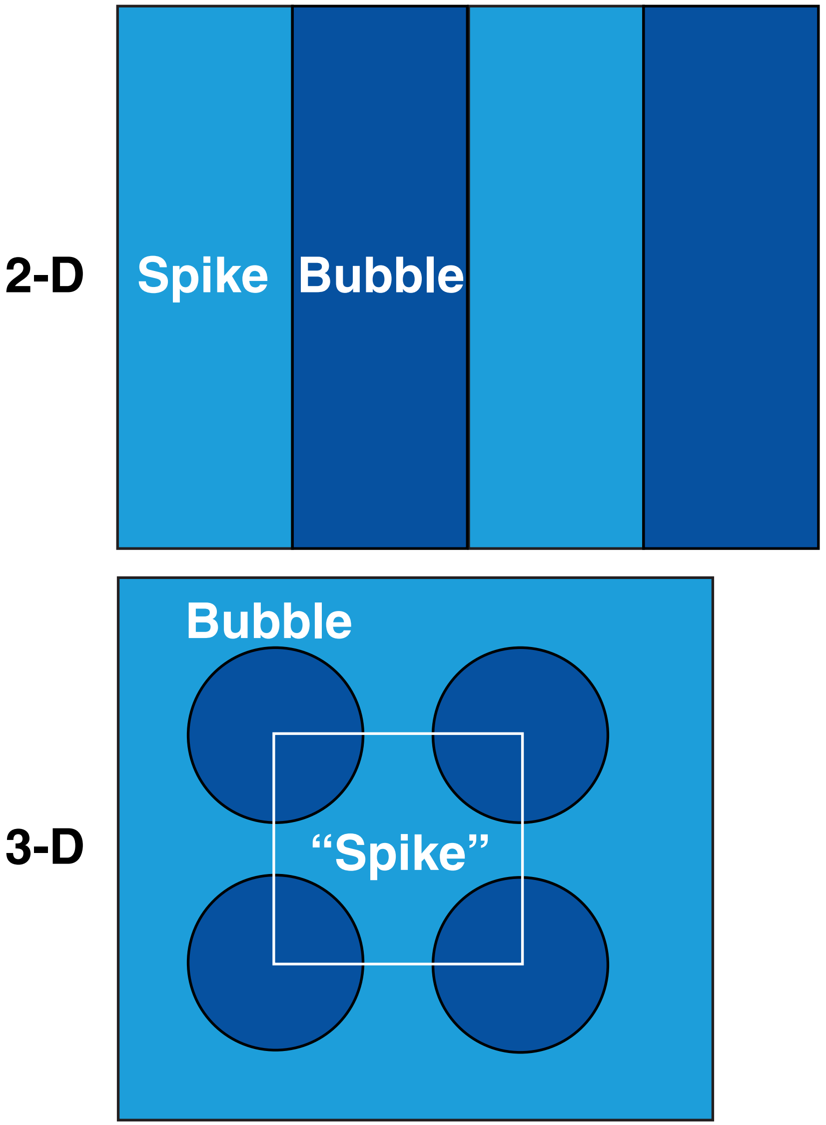
Grid: 100 × 100 × 1200

*R. Betti and J. Sanz, Phys. Rev. Lett. 97, 205002 (2006).

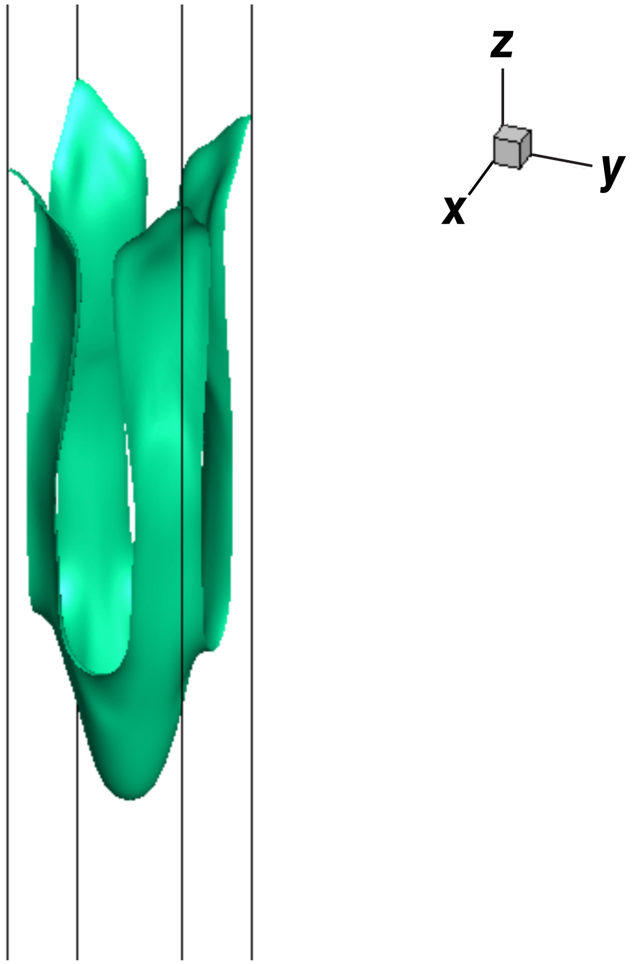
TC12206

Three-dimensional topology is significantly different from 2-D

Top views

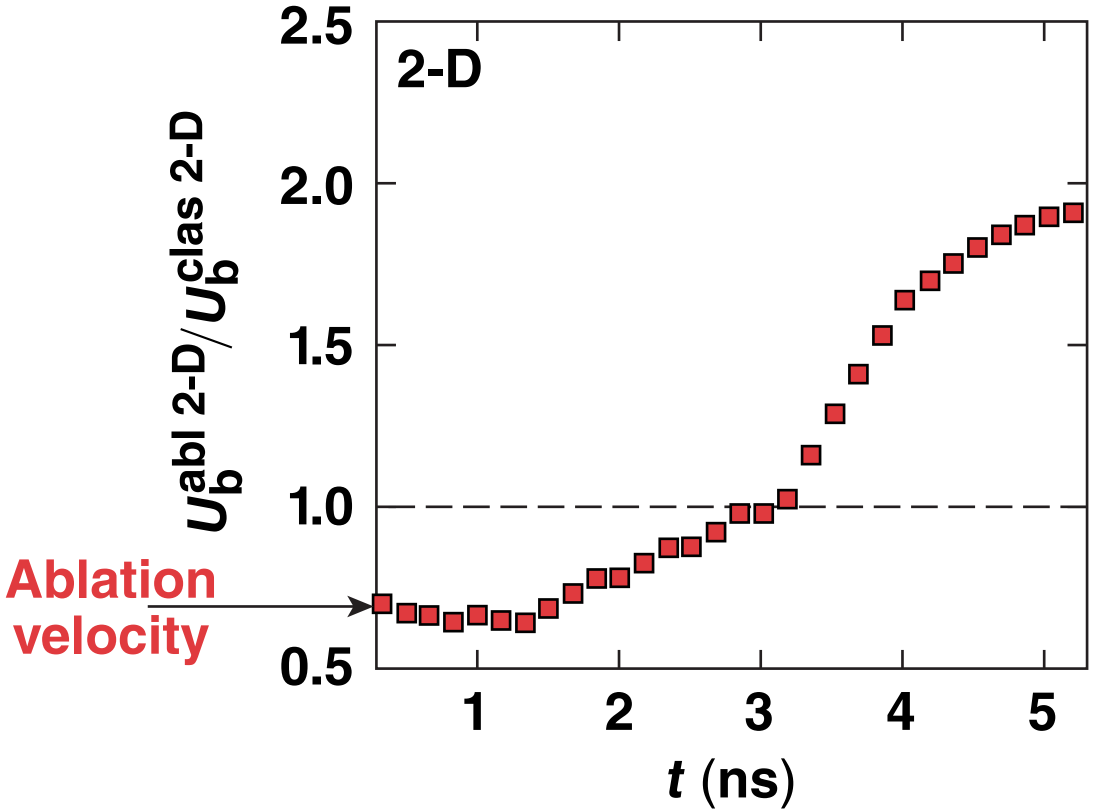


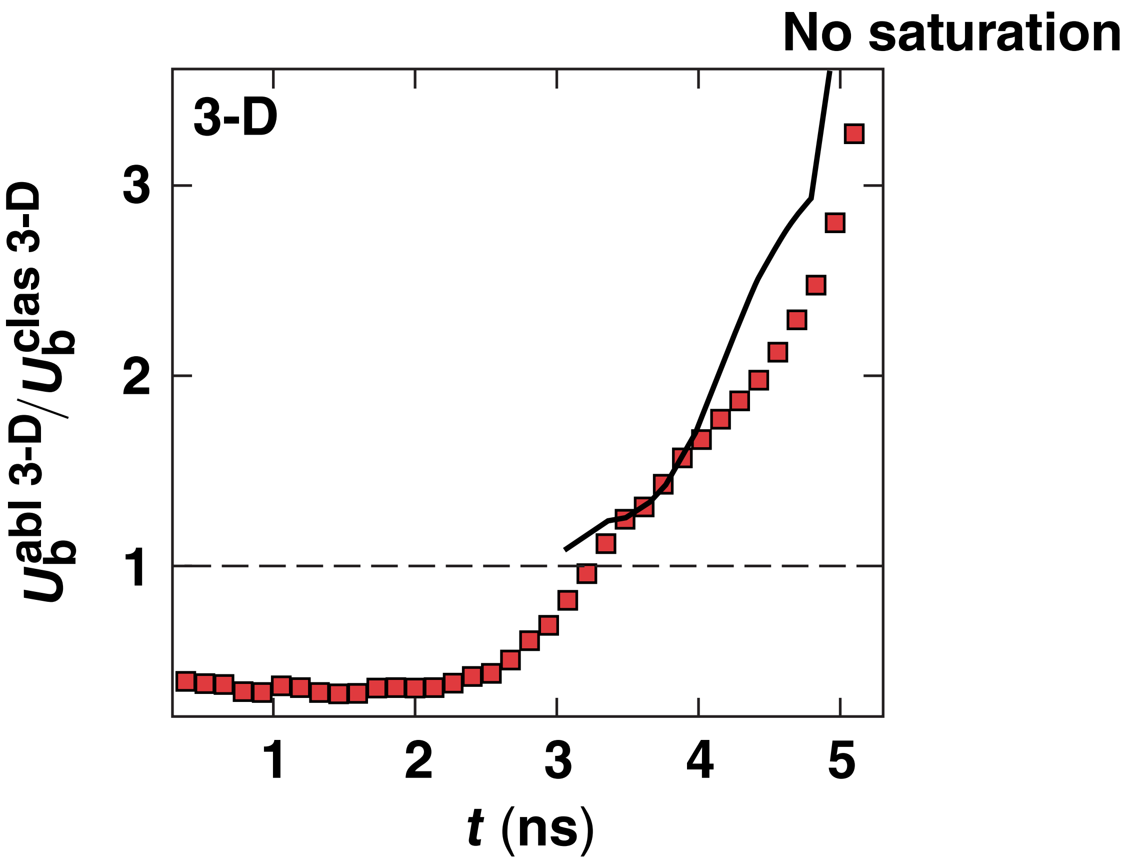
Isodensity surface of $\rho = 3\ \text{g/cm}^3$ at $t = 5.4$ ns in the 3-D simulation



TC11582a

Unlike in 2-D, the 3-D bubble velocity does not show saturation in the ablative RTI





$$U_b^{clas\ 2\text{-}D} = \sqrt{g\left(1-\rho_l/\rho_h\right)/3k}\ ^*$$

$$U_b^{clas\ 3\text{-}D} = \sqrt{g\left(1-\rho_l/\rho_h\right)/k}\ ^*$$

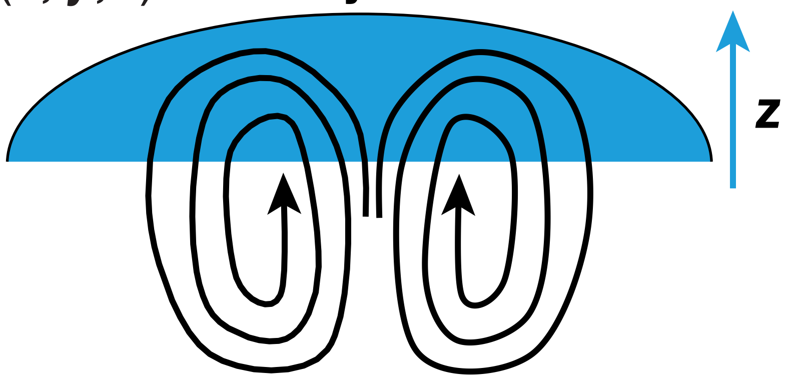
*V. N. Goncharov, Phys. Rev. Lett. 88, 134502 (2002).

TC12410

The Layzer model* in 3-D is extended by adding vortices inside the bubble

Model including vortices**

$z = \eta(x, y, t)$ Heavy fluid



$$\vec{v}_\ell = \nabla \phi_\ell + \hat{e}_z [\cos(kx) + \cos(ky)] \omega_0 / k$$

$$\omega_0 \sim v_{abl} k f_k(t)$$

$$f_k(t) \begin{cases} \text{Saturated in 2-D} \\ \text{Not saturated in 3-D} \end{cases}$$

Steady 3-D bubble velocity:

$$U_b^{rot\ 3\text{-}D} = \sqrt{\frac{g(1-r_d)}{k} + \frac{r_d \omega_0^2}{k^2}}$$

Classical Vortex

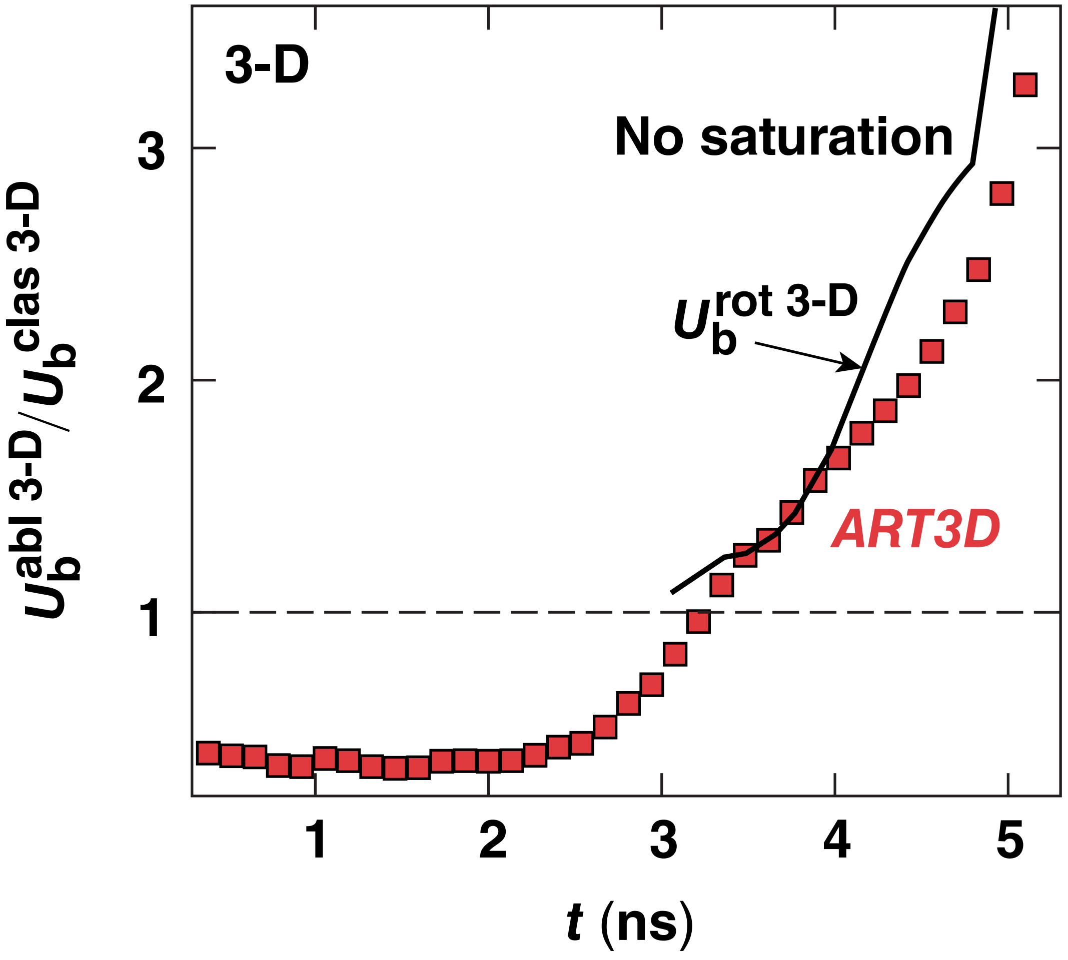
$$r_d = \rho_\ell / \rho_h$$

* D. Layzer, Astrophys. J. 122, 1 (1955).
** R. Betti and J. Sanz, Phys. Rev. Lett. 97, 205002 (2006).

TC12411

The modified Layzer model shows good agreement with the 3-D simulation results

3-D bubble velocity for $\lambda = 10\ \mu m$



Asymptotic bubble velocities:

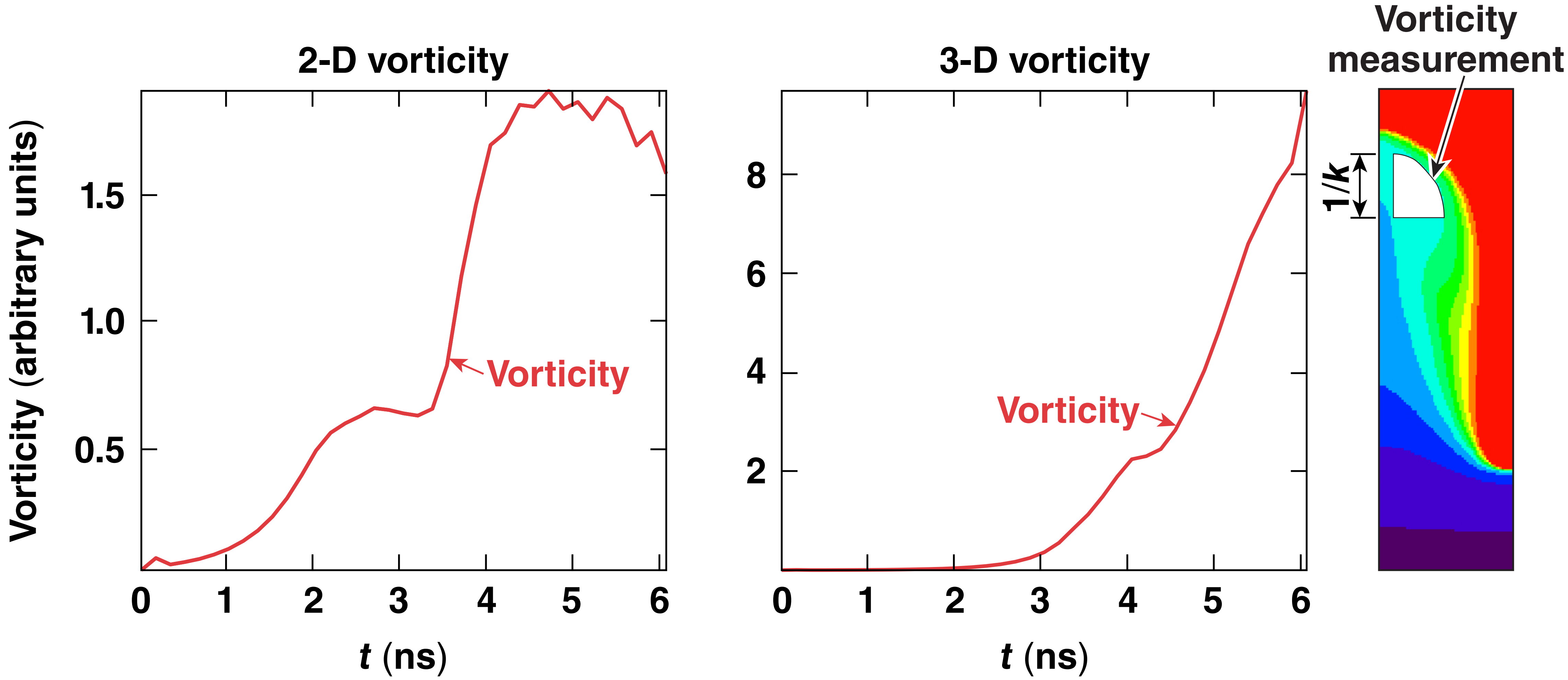
$$U_b^{rot\ 3\text{-}D} = \sqrt{g(1-r_d)/k + r_d\,\omega_0^2/k^2}$$

$$U_b^{clas\ 3\text{-}D} = \sqrt{g(1-r_d)/k}$$

g, ω_0, and r_d are taken from the simulation

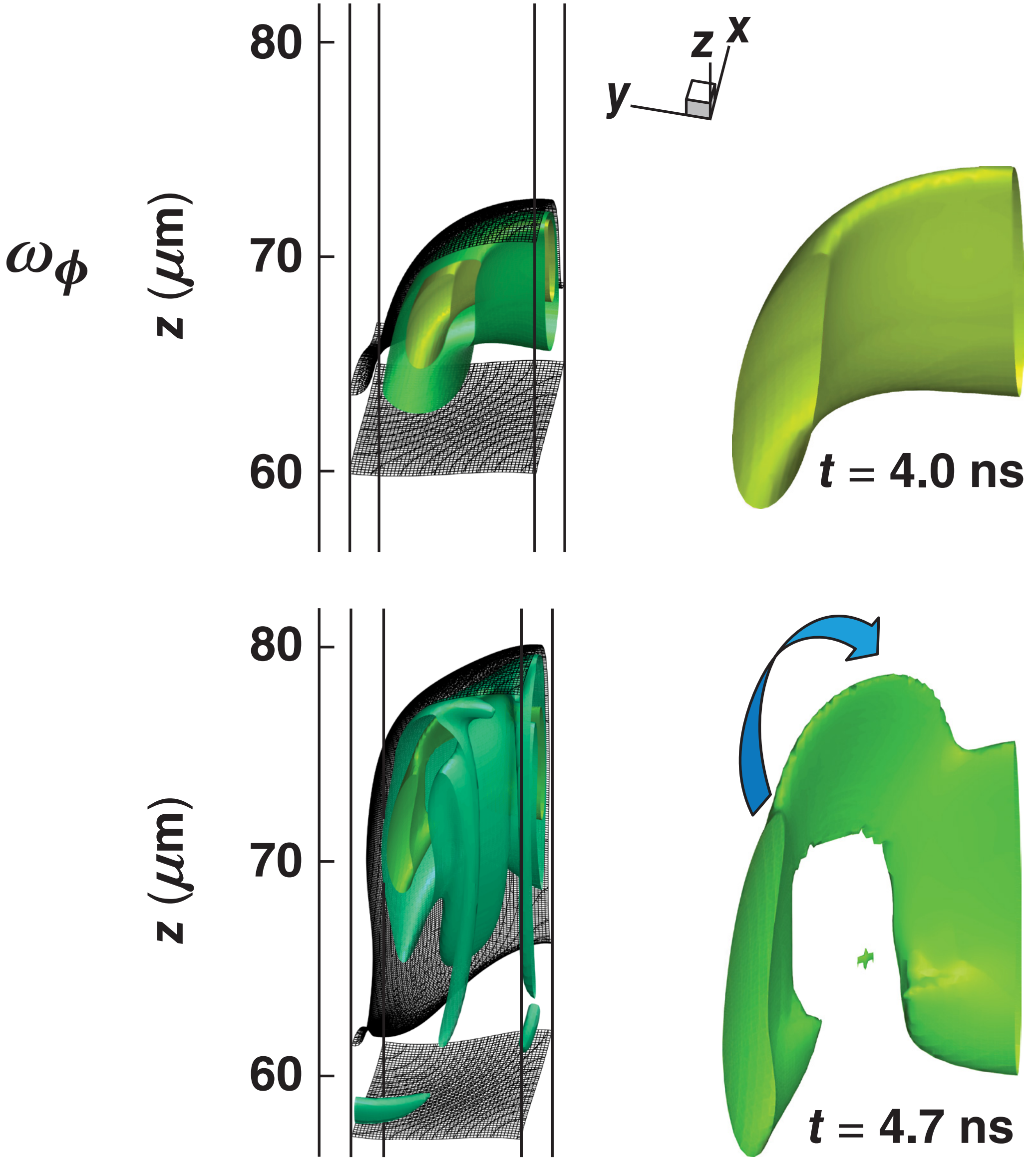
TC12412

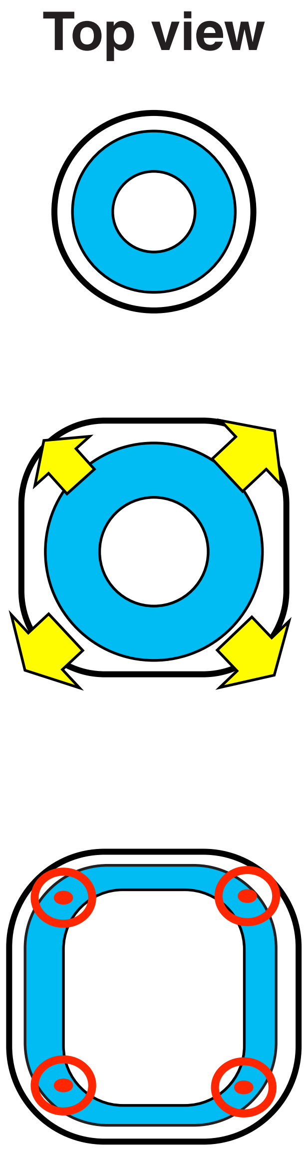
The vorticity near the bubble tip saturates in 2-D but continues to increase in 3-D



TC11584

The bubble and the vortex inside the bubble become distorted in the highly nonlinear phase

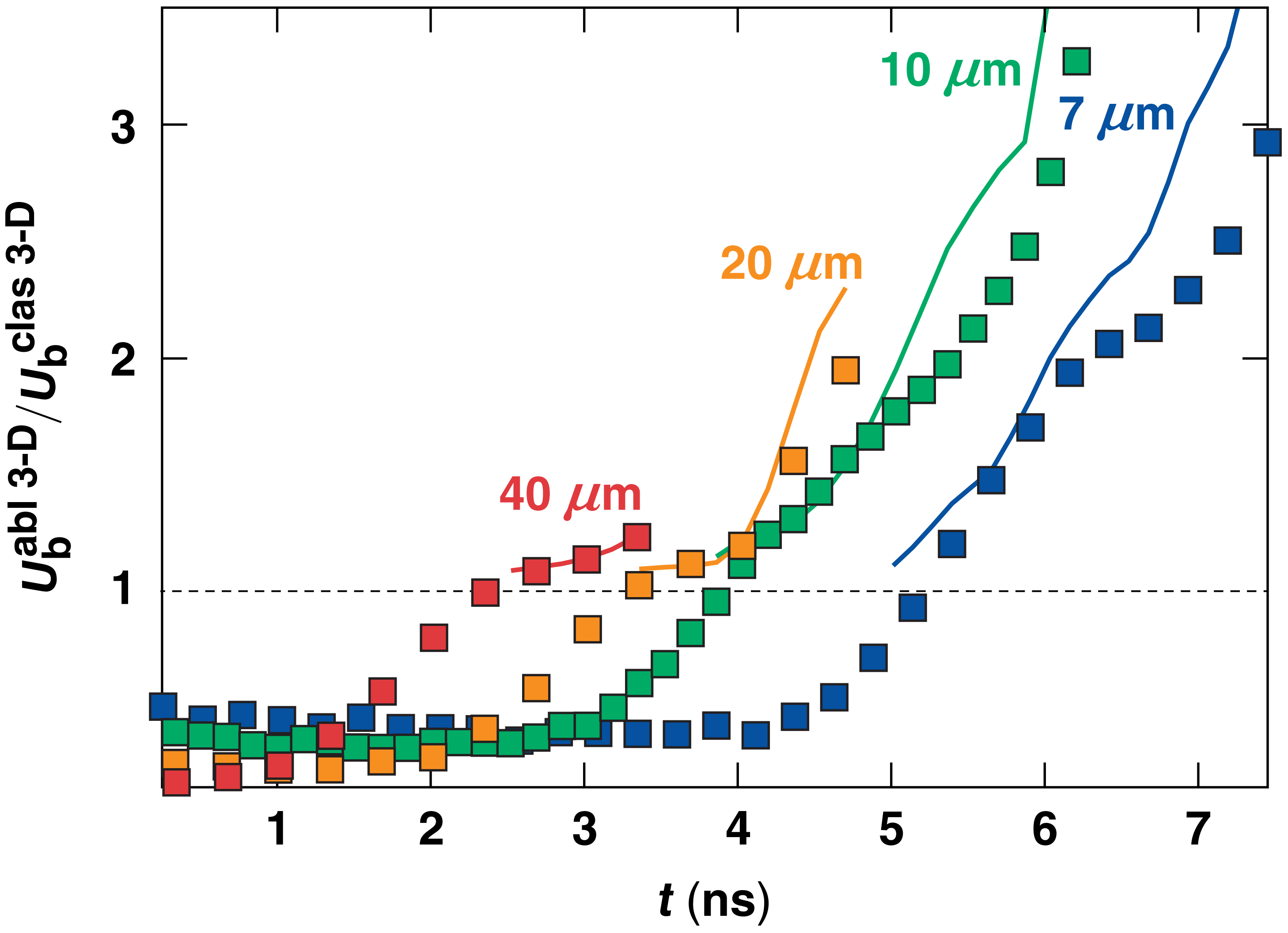




Folding the corners of the vortex ring can increase the vorticity near the bubble tip.

TC12208

The bubble acceleration is stronger for shorter wavelengths and does not show saturation



TC12209

Three-dimensional simulations show that the bubble growth in the ablative Rayleigh–Taylor instability (RTI) is faster than classical RTI predictions

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