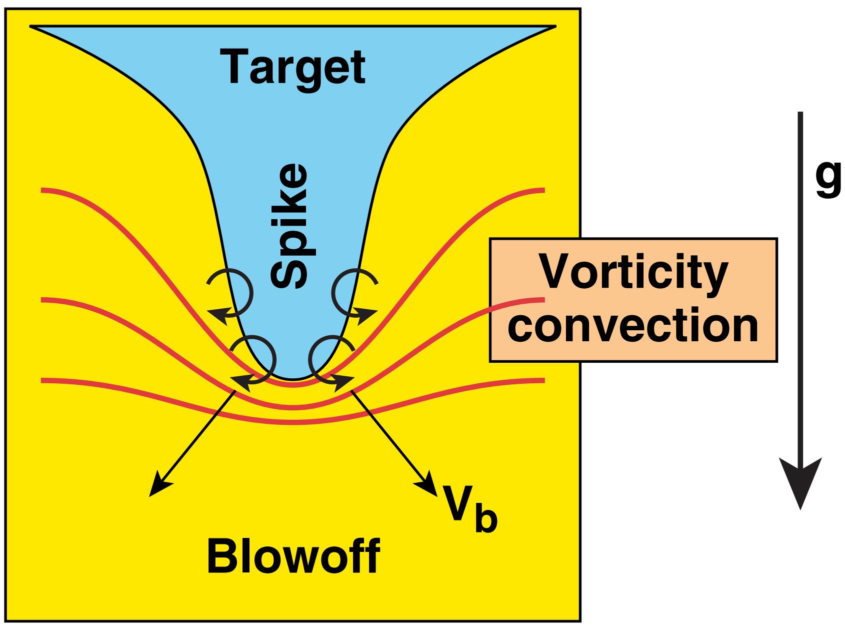
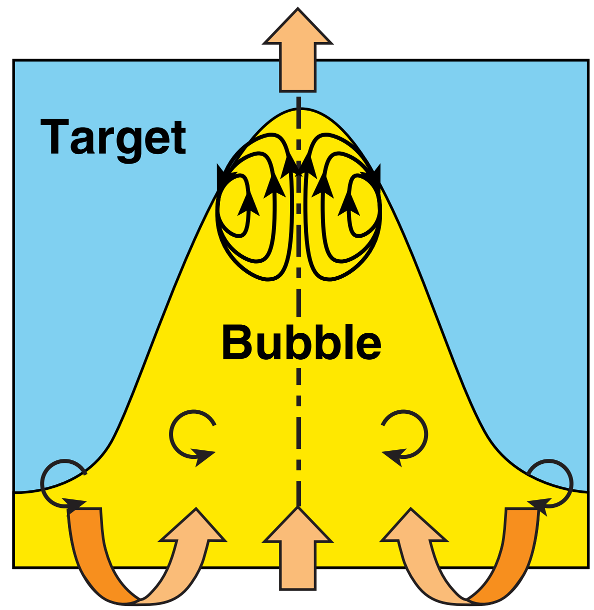
Bubble Acceleration in the Ablative Rayleigh–Taylor Instability (RTI)

Vorticity is convected from the ablation front.

Vorticity accumulates in the bubble. The bubble accelerates.





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Summary

In the ablative RTI, the terminal bubble velocity is significantly larger than predicted by classical theory; ablation is nonlinearly destabilizing

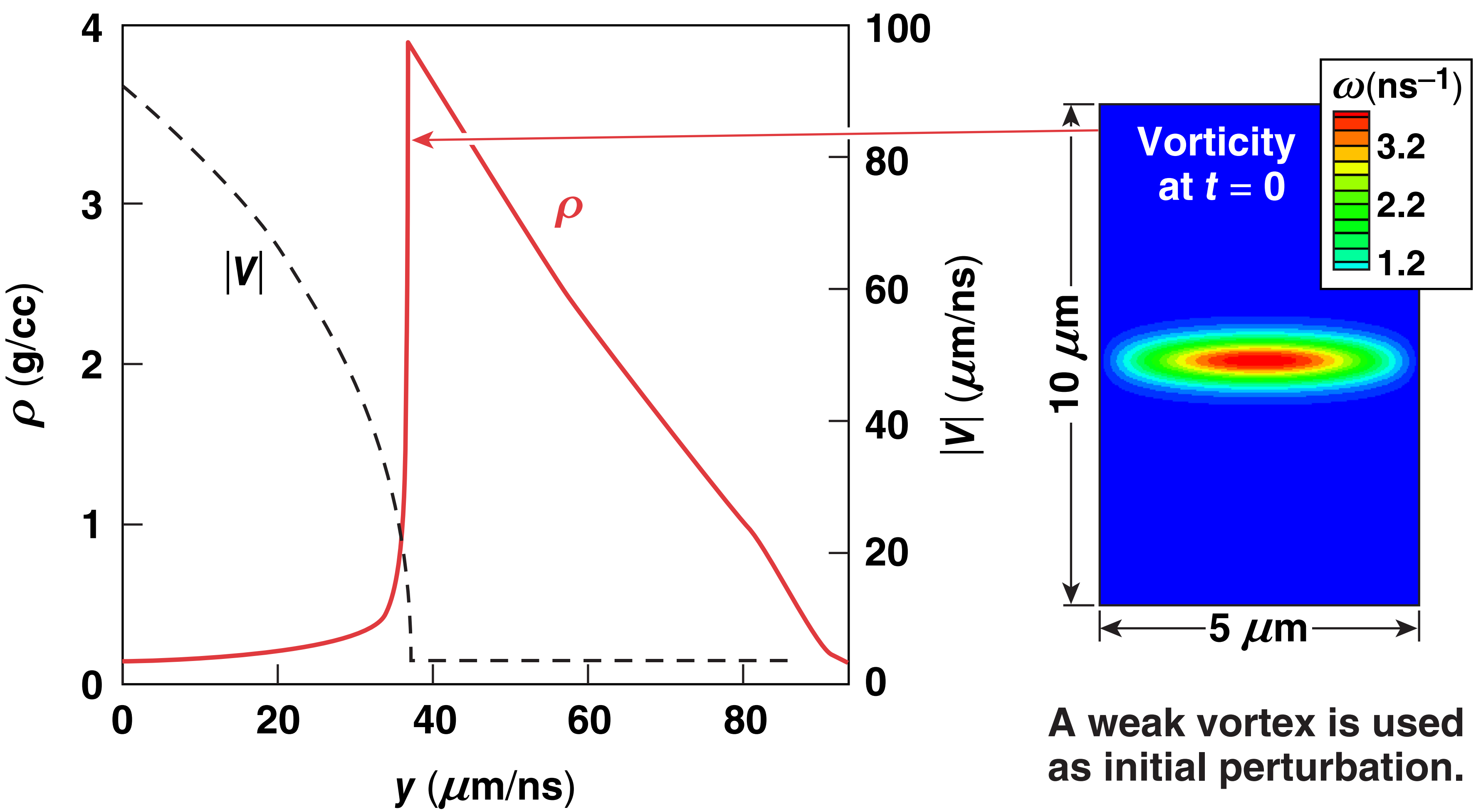
- The vorticity convected off the ablation front fills the rising bubble.
- The centrifugal force of the rotating flow in the vortex pushes the bubble to higher velocities.
- The terminal bubble velocity is approximately

$$V_{\text{bubble}}^{\text{2-D}}(\infty) \approx \sqrt{\frac{g}{3k}\left(1 - r_d\right) + \frac{V_a^2}{r_d}} \qquad r_d = \frac{\rho_{\text{bubble}}}{\rho_{\text{dense}}}$$

TC7555

R. Betti and J. Sanz, to be published in Phys. Rev. Lett.

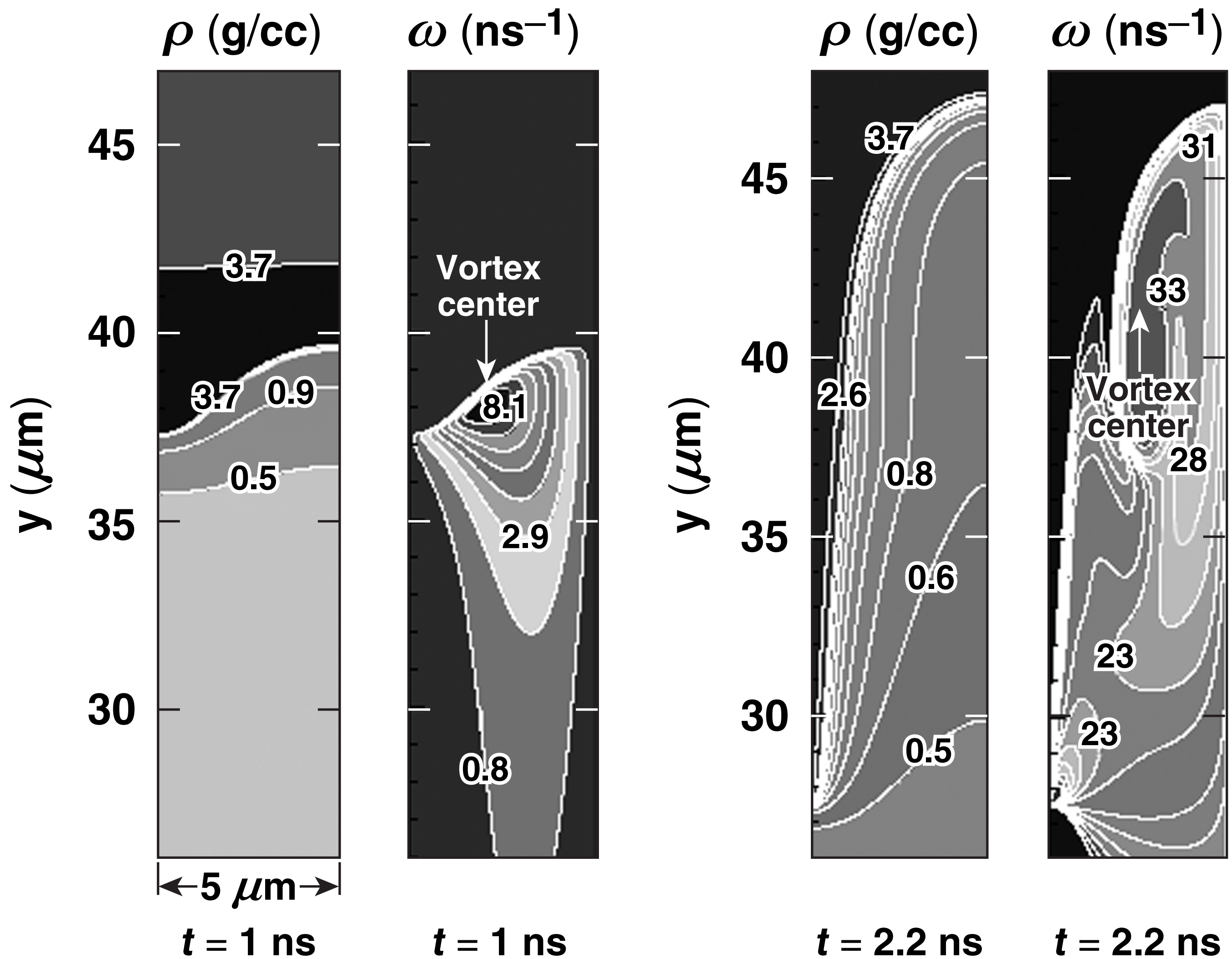
The single-mode ablative Rayleigh–Taylor instability is simulated for the NIF direct-drive point design using the code *ART* with a 210 × 4000 grid



A weak vortex is used as initial perturbation.

TC7556

Simulations show vorticity convection and accumulation



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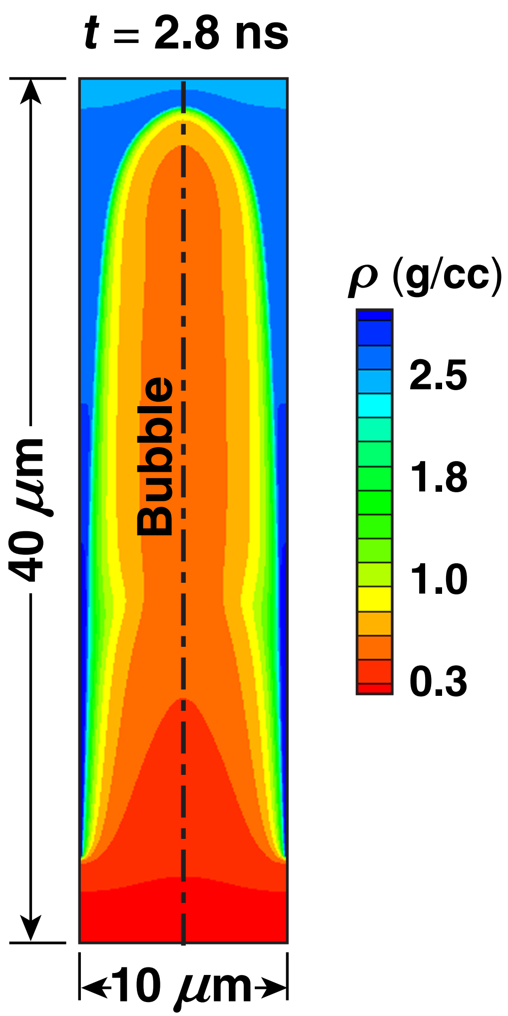
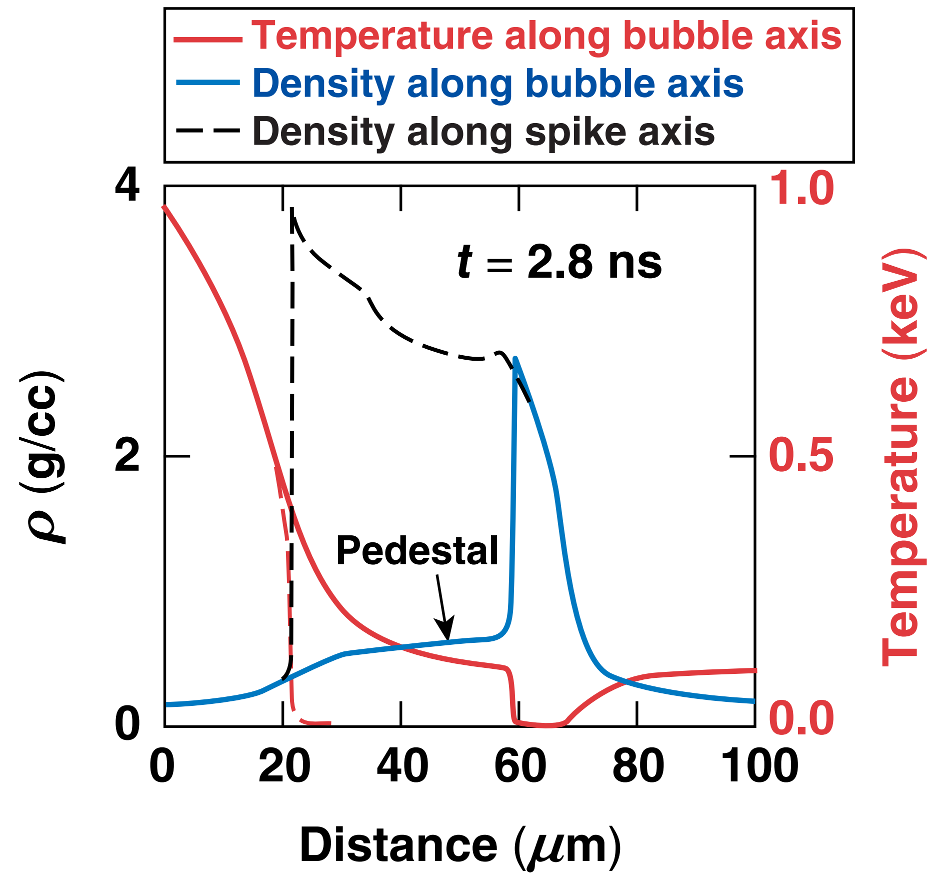
A density pedestal forms inside the bubble and a new ablation front is established between the spikes





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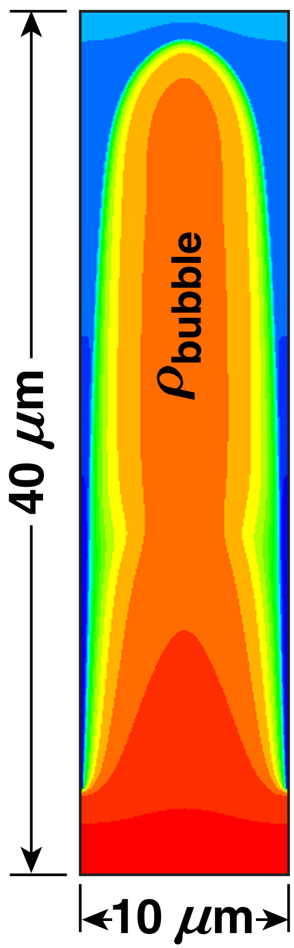
The density in the bubble is the same as predicted by the linear theory* and a significant fraction of the dense target density



$$\rho_{\text{bubble}}^{\text{linear}} \approx (0.1\, kL_m)^{2/5} \rho_{\text{dense}}$$

$$\rho_{\text{dense}} \approx 4 \text{ g/cc}$$

$$L_m \approx 0.18\ \mu\text{m} \qquad \lambda \approx 10\ \mu\text{m}$$

$$\rho_{\text{bubble}}^{\text{linear}} \approx 0.66 \text{ g/cc}$$

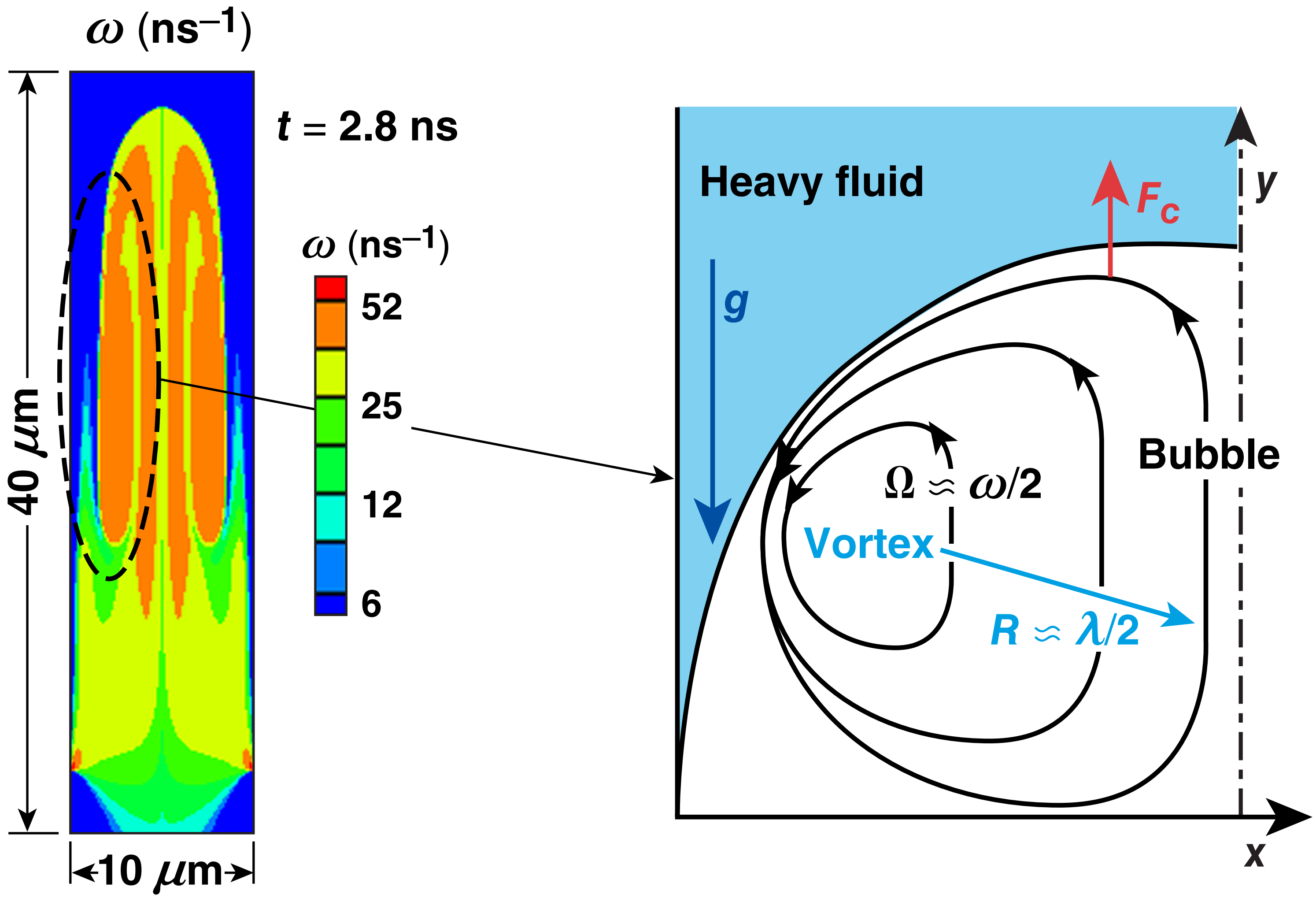
$$\rho_{\text{bubble}}^{\text{simulation}} \approx 0.65 \text{ g/cc}$$

L_m = the minimum density-gradient scale length
k = mode wave number

TC7559

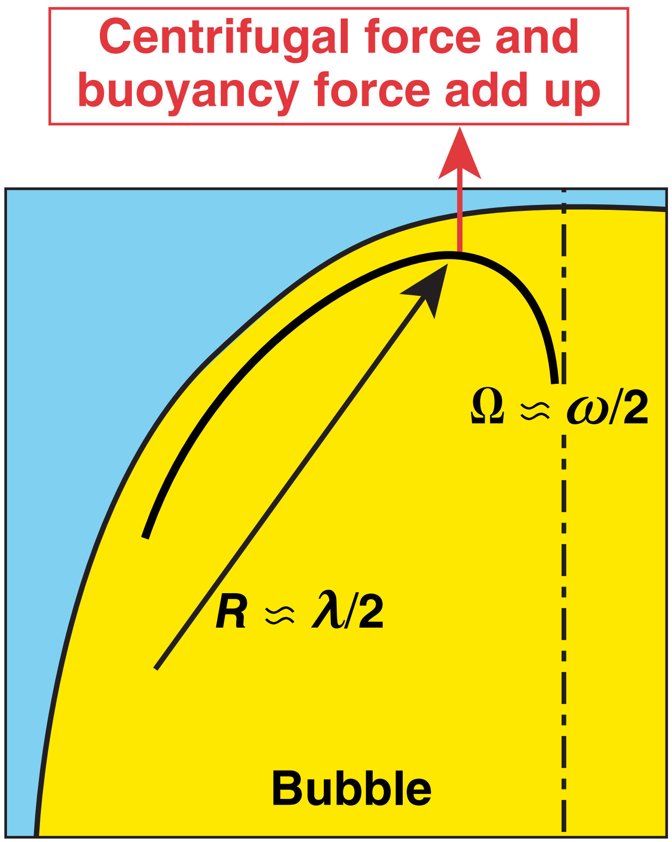
*R. Betti *et al.*, Phys. Plasmas 2, 2122 (1996).

A large vortex forms inside the bubble; the vortex generates a centrifugal force (F_c) pushing on the bubble tip



TC7560

The asymptotic bubble velocity is higher than the classical value due to the vorticity accumulated inside the bubble



$$r_d = \frac{\rho_{\text{bubble}}}{\rho_{\text{dense}}}$$

Centrifugal force:

$$\rho_{\text{bubble}} R\Omega^2 = \rho_{\text{bubble}} \frac{R\omega^2}{4}$$

Buoyancy force:

$$\left(\rho_{\text{dense}} - \rho_{\text{bubble}}\right) g$$

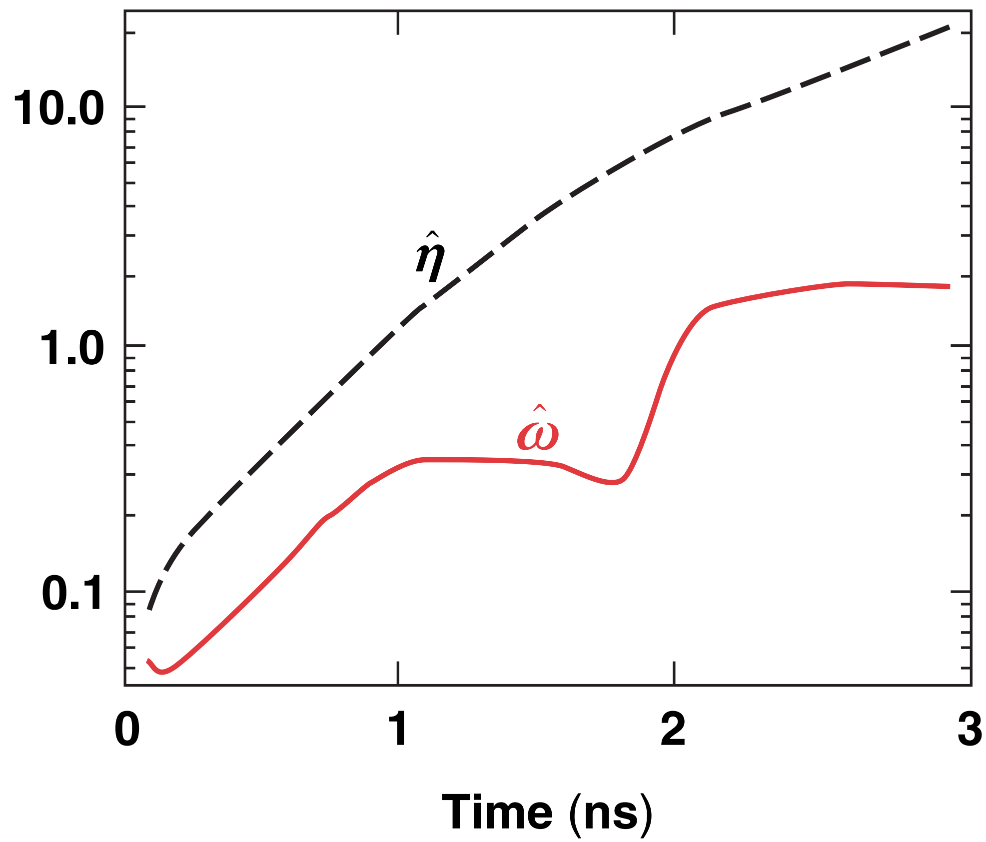
$$V_{\text{bubble}}^{\text{vort}} = \sqrt{\frac{g}{3k}\left(1 - r_d\right) + r_d \frac{\omega^2}{4k^2}}$$

Bubble-velocity enhancement

After a first plateau starting when $\eta \approx 0.1\lambda$, the vorticity in the bubble increases; saturation occurs when $\omega \approx 2\ kV_a/r_d$

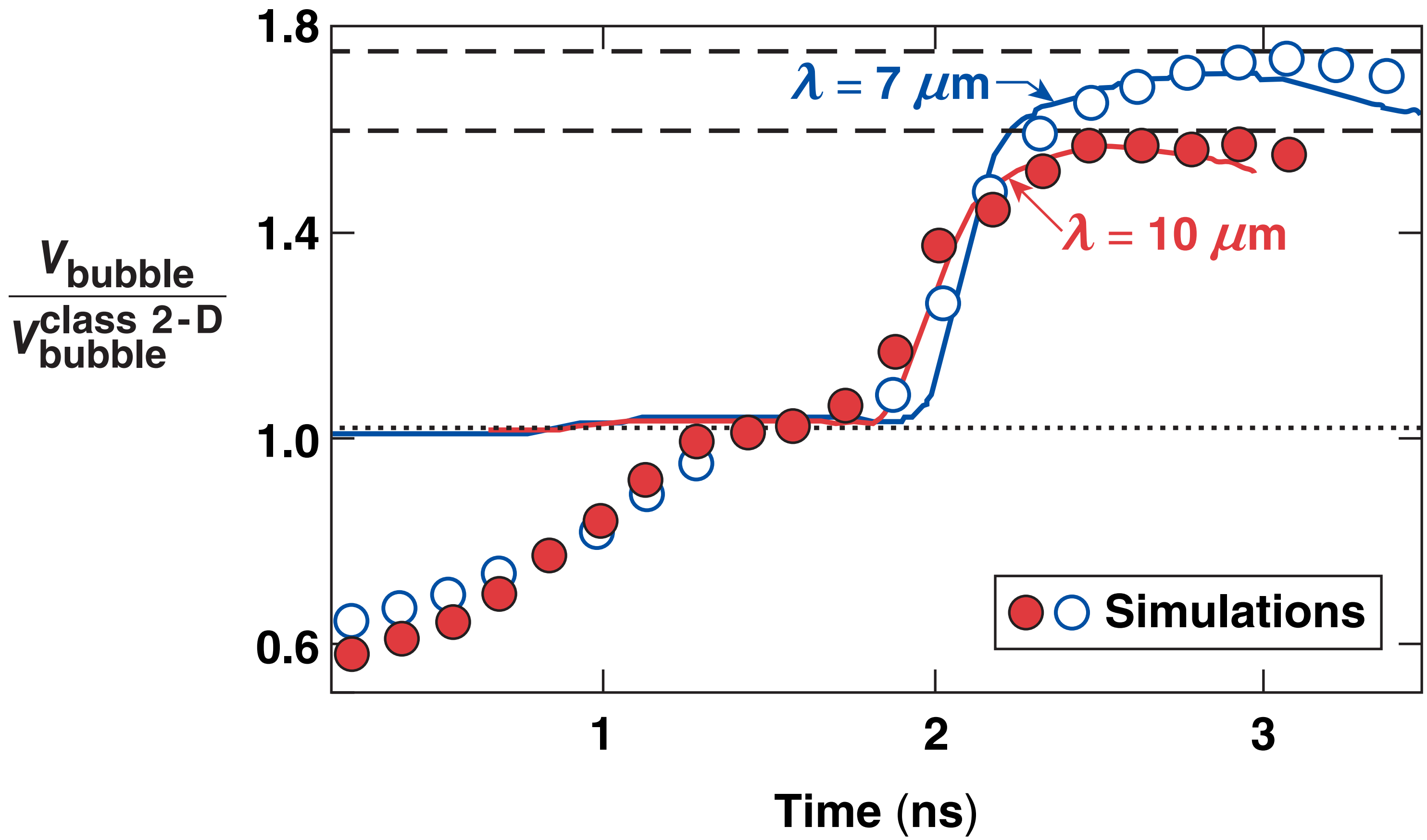
$$\hat{\eta} = \frac{\overbrace{0.5\left(y_{\mathrm{bubble}} - y_{\mathrm{spike}}\right)}^{\eta}}{0.1\lambda}$$

$$\hat{\omega} = \frac{\omega}{kV_a/r_d}$$



TC7563

The bubble accelerates to final velocities well above the classical value and in agreement with the theory



— $\sqrt{\frac{g}{3k}(1-r_d)+r_d\frac{\omega(t)^2}{4k^2}}$ – – $\sqrt{\frac{g}{3k}(1-r_d)+\frac{V_a^2}{r_d}}$

TC7564

Summary/Conclusions

In the ablative RTI, the terminal bubble velocity is significantly larger than predicted by classical theory; ablation is nonlinearly destabilizing

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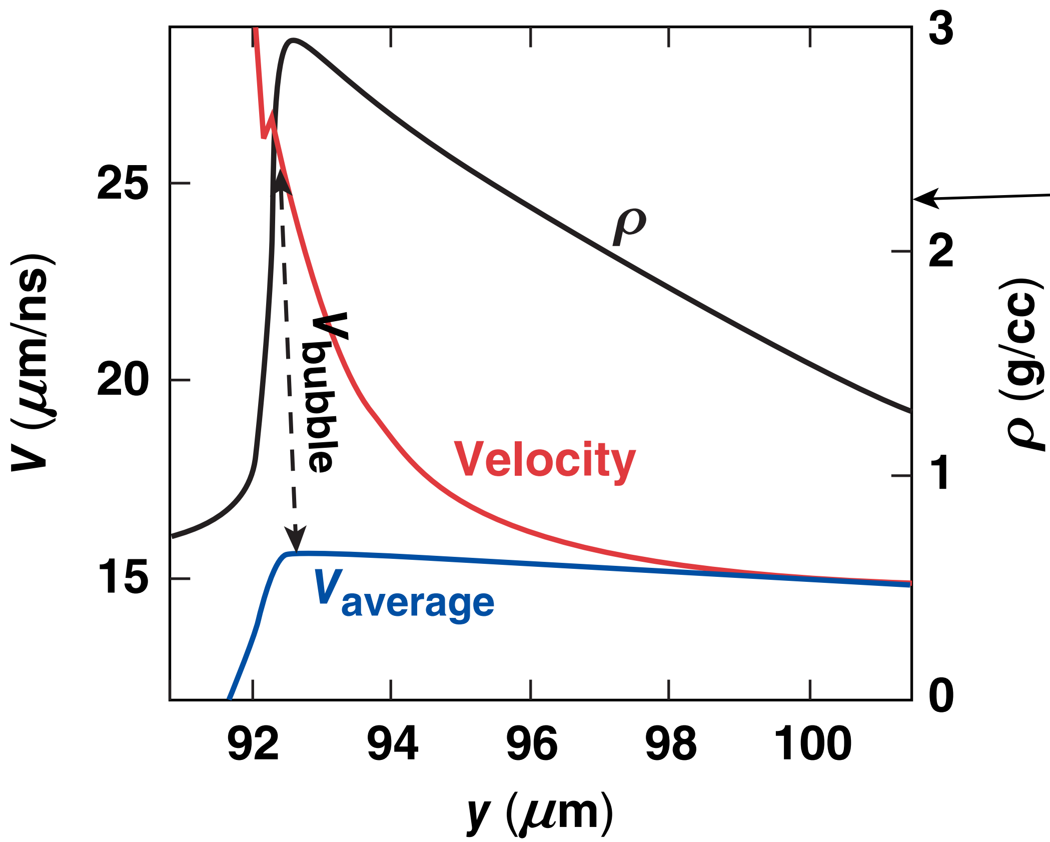
- The vorticity convected off the ablation front fills the rising bubble.
- The centrifugal force of the rotating flow in the vortex pushes the bubble to higher velocities.
- The terminal bubble velocity is approximately

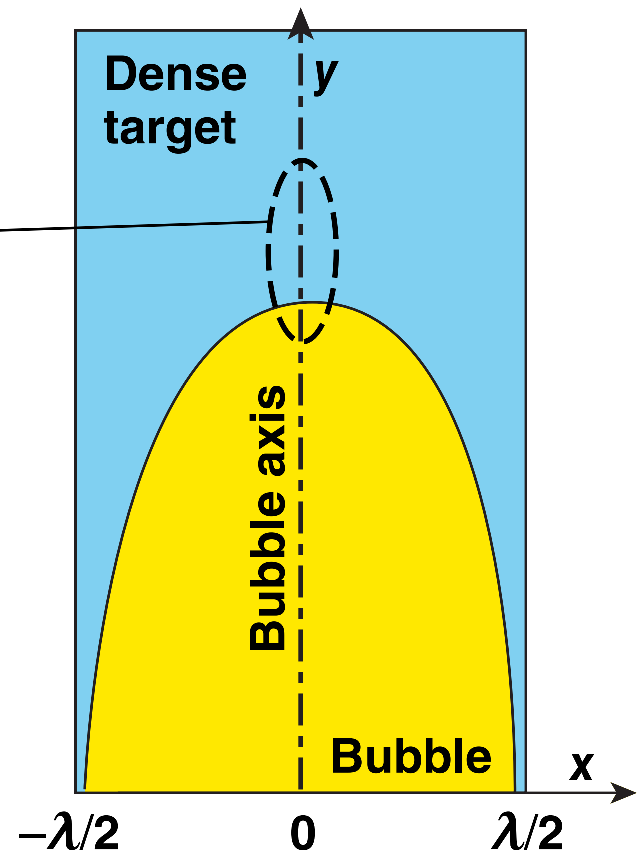
$$\boxed{V_{\text{bubble}}^{2\text{-D}}(\infty) \approx \sqrt{\frac{g}{3k}(1 - r_d) + \frac{V_a^2}{r_d}}} \qquad r_d = \frac{\rho_{\text{bubble}}}{\rho_{\text{dense}}}$$

- Will the ablation-induced vorticity affect the multimode bubble-front growth $\alpha g t^2$?

R. Betti and J. Sanz, to be published in Phys. Rev. Lett.

The bubble velocity is defined as the penetration velocity inside the overdense target





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