3D Single-mode Nonlinear Ablative Rayleigh-Taylor Instability for ICF

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Abstract

The nonlinear evolution of the ablative Rayleigh-Taylor (ART) instability is studied in three-dimensions for conditions relevant to inertial confinement fusion (ICF) targets. The simulations are performed using our newly developed code *ART3D* and an astrophysical code *AstroBEAR*.

Simulation setup

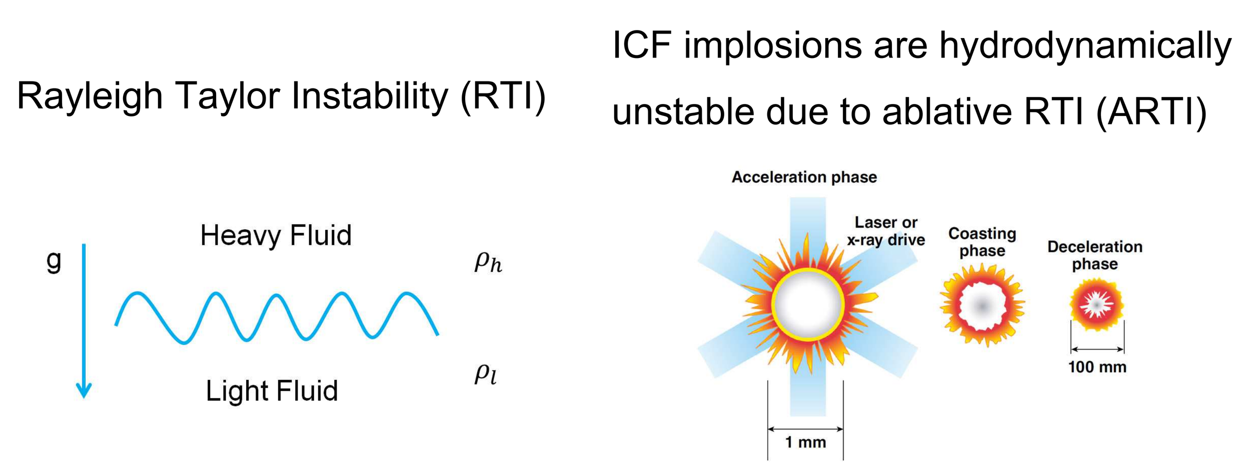
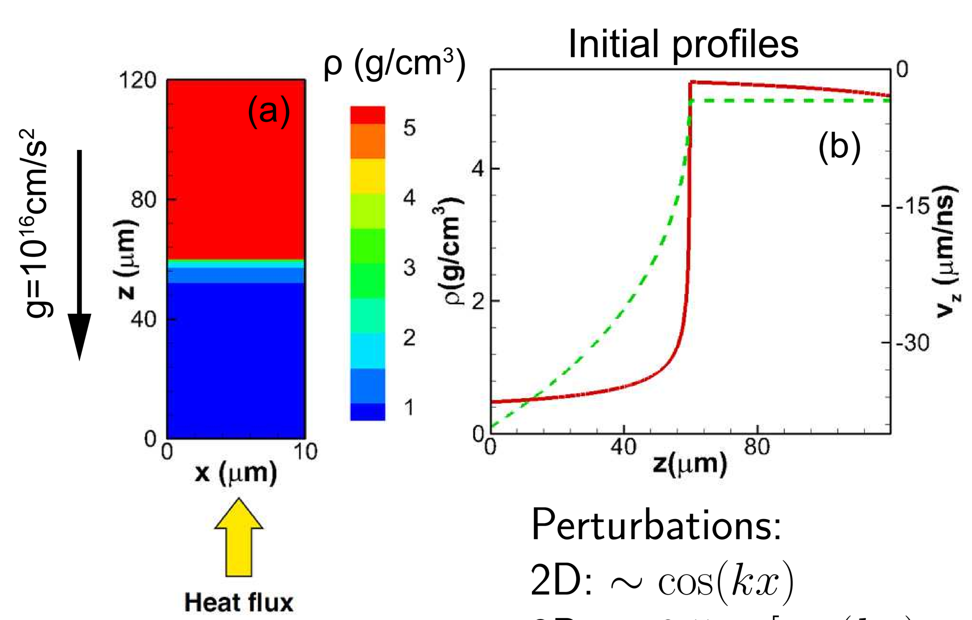
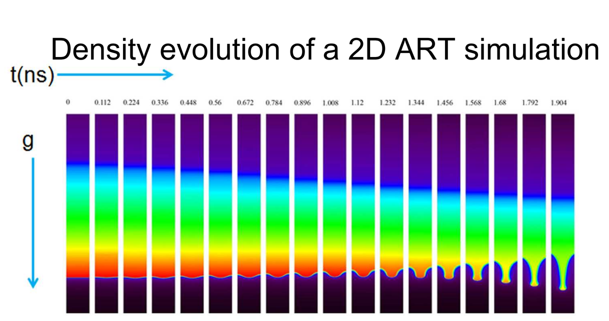


Figure 1: Schematic of the Rayleigh Taylor instability and its presence in ICF



Perturbations:
2D: $\sim \cos(kx)$
3D: $\sim 0.5 \times [\cos(kx) + \cos(ky)]$

Figure 2: The simulation setup for the *ART3D* simulation with $\lambda = 10\mu m$. (a) The contour is the initial density profile. (b) The initial ρ (solid) and v_z (dashed) profiles along the z axis.



Gravity $\vec{g}$ is adjusted in flight to keep the shell's position quasi-static

Figure 3: Density evolution of a 2D *ART* simulation.

http://astrobear.pas.rochester.edu

RT Bubble is accelerated by the vortex due to ablation, more significantly in 3D

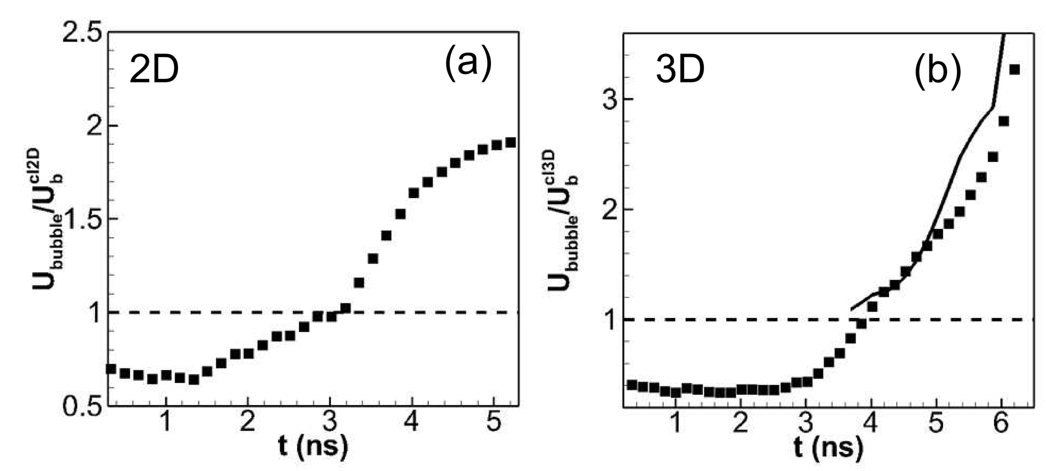


Figure 4: Ratio of the bubble velocities to the classical bubble velocities from the 2D (a) and 3D (b) *ART* simulations for the perturbation wavelength $\lambda = 10\mu m$ (square). The solid line is given by U_b^{rot3D} in Fig. 6.
The 2D result shows a saturation on the bubble velocity while the 3D result shows no saturation.

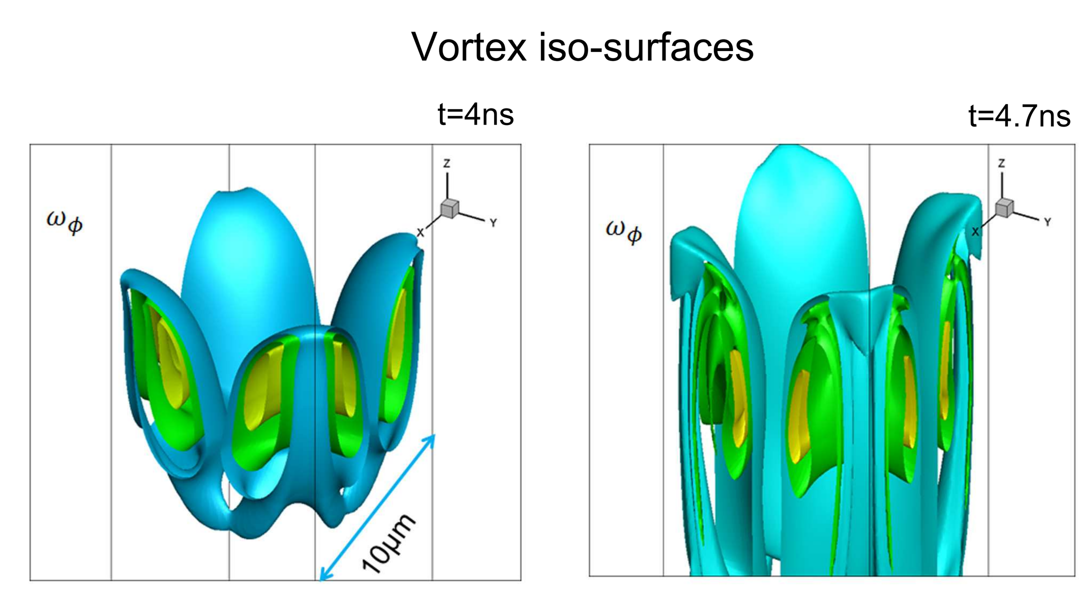
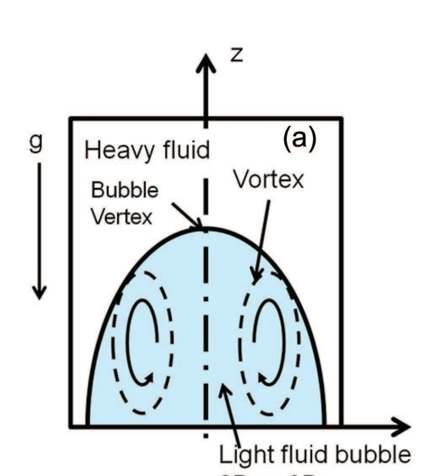


Figure 5: Azimuthal vortex $\omega_\phi = \sqrt{\omega_x^2 + \omega_y^2}$ in the 3D bubble in an *ART3D* simulation.
The distortion of the vortex enhances the bubble acceleration in 3D



(b)

$$U_b^{cl2D} = \sqrt{g(1-r_d)/3k}$$
$$U_b^{cl3D} = \sqrt{g(1-r_d)/k}$$
$$U_b^{rot3D} = \sqrt{\frac{g(1-r_d)}{k} + r_d\frac{\omega_0^2}{k^2}}$$
$$r_d = \rho_l/\rho_h.$$

Figure 6: Theoretical model. U_b^{cl} are the asymptotic bubble velocities for classical (no ablation) RT. U_b^{rot3D} is the 3D bubble velocities with the vortex acceleration mechanism taken into account. The 2D version of this model has been verified in Ref. [1].

Bubble acceleration due to vortex is stronger for shorter-wavelength modes

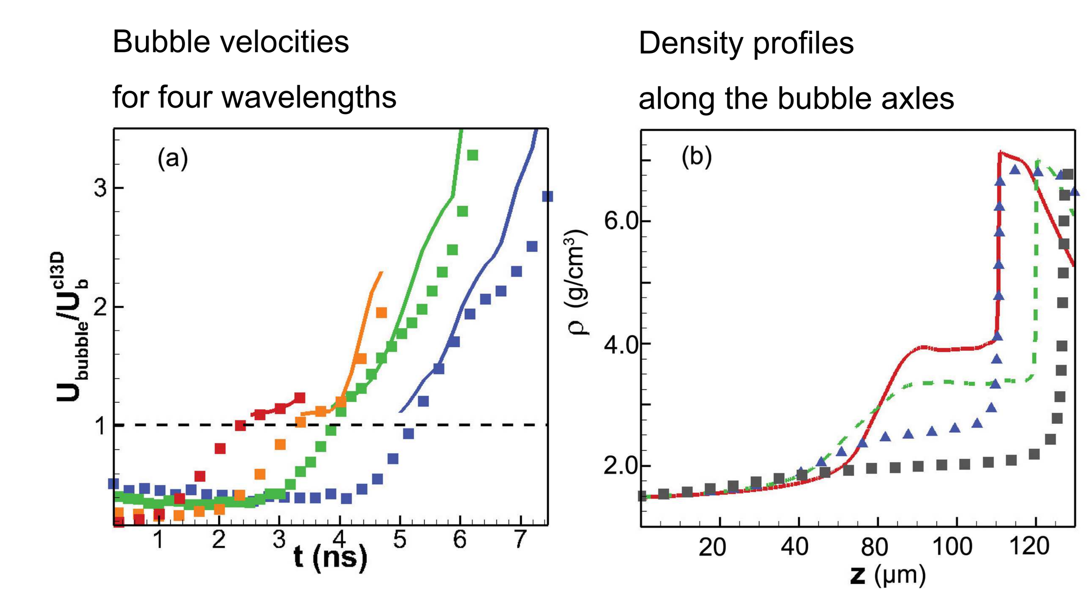


Figure 7: (a) The bubble velocities from *ART3D* (square) compared with U_b^{rot3D}(solid line) for $\lambda = 40$(red), 20(orange), 10(green), 7(blue) μm, respectively. (b) The density profiles along the bubble axle. Solid: $\lambda = 7\mu m$ at $t = 6.8ns$; dashed: $\lambda = 10\mu m$ at $t = 5.7ns$; delta: $\lambda = 20\mu m$ at $t = 4.2ns$; square: $\lambda = 40\mu m$ at $t = 4.2ns$

Good agreement is reached between *ART3D* and *AstroBEAR*

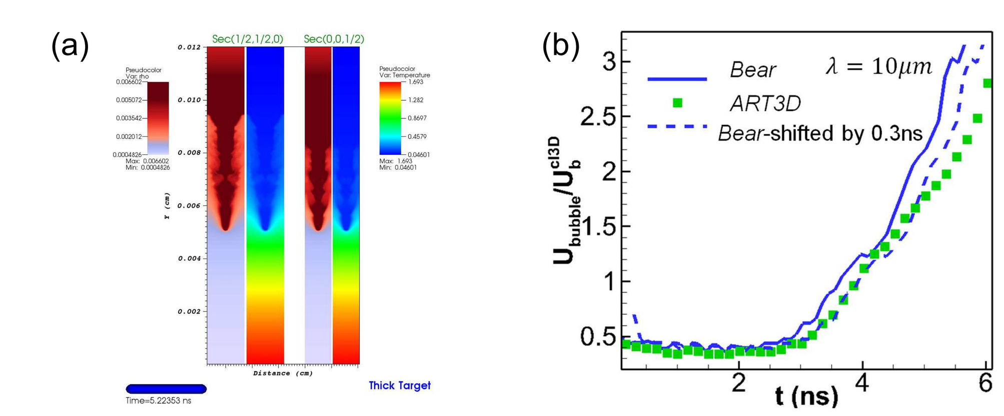


Figure 8: (a) The snapshot of density and temperature along the diagonal slice at $t = 5.2ns$ of the *AstroBEAR* simulation; (b) comparison of the bubble velocities between *AstroBEAR* and *ART3D*.

Conclusion

As the mode wavelength approaches the cutoff of the linear spectrum (short wavelength modes), it is found that the bubble velocity grows faster than predicted in the classical 3D theory. When compared to two-dimensional results, 3D short-wavelength bubbles grow faster and do not reach saturation. The unbounded 3D bubble acceleration is driven by the unbounded accumulation of vorticity inside the bubble. The vorticity is transferred by mass ablation from the Rayleigh-Taylor spikes into the ablated plasma filling the bubble volume. A density plateau is observed inside a nonlinear ART bubble and the plateau density is higher for shorter-wavelength modes.

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