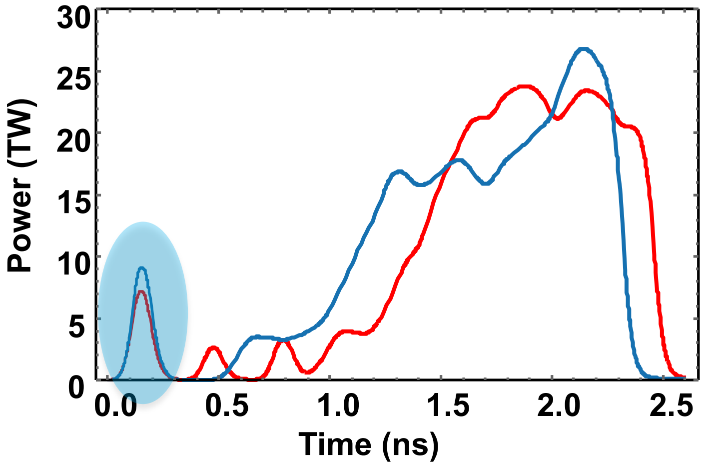
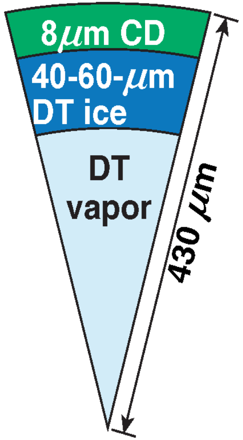
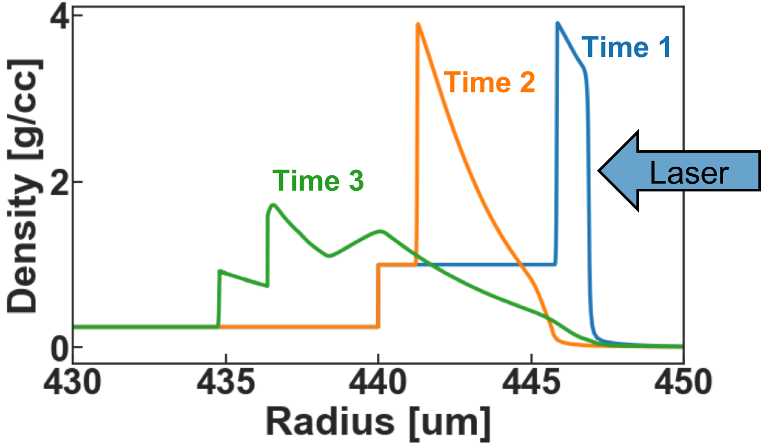
A Study of Internal Perturbation Evolution in Inertial Confinement Fusion Implosions







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- ICF targets have internal defects like voids, and surface roughness that seed perturbations that degrade performance through instability growth
- Internal acoustic waves (e.g. compression/rarefaction waves) carry perturbation information throughout the shell
- Perturbations caused by internal defects are exponentially amplified by convergent characteristics
- Perturbation amplification does not follow the predicted trend in finite-difference-based fluid solvers, but is recovered when the Finite Volume Local Evolution Galerkin (FVLEG[1]) scheme is used

[1] Y. Sun, Y.X. Ren, J. Comp. Phys. 228 4945 (2009)

Collaborators

V. N. Goncharov, T. J. B. Collins, J. A. Marozas,

A. Shvydky, J. Carroll-Nellenback, P. B. Radha

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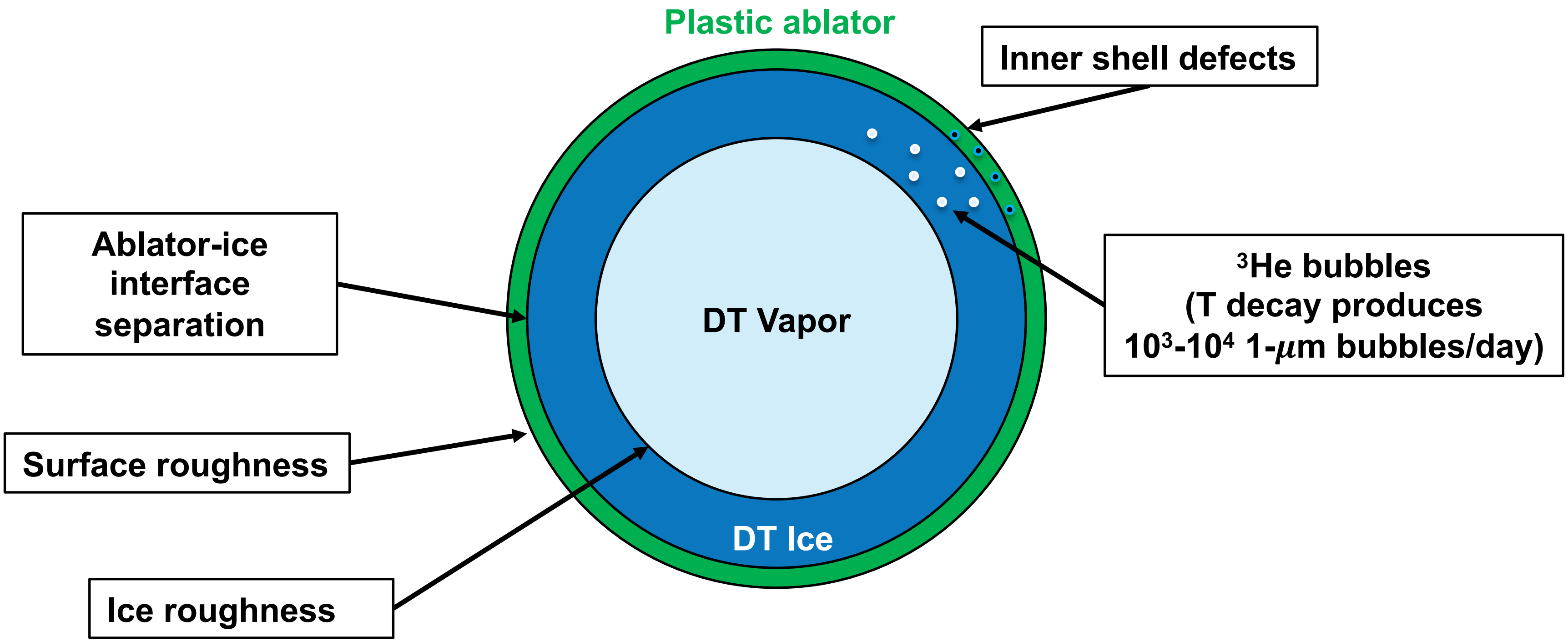
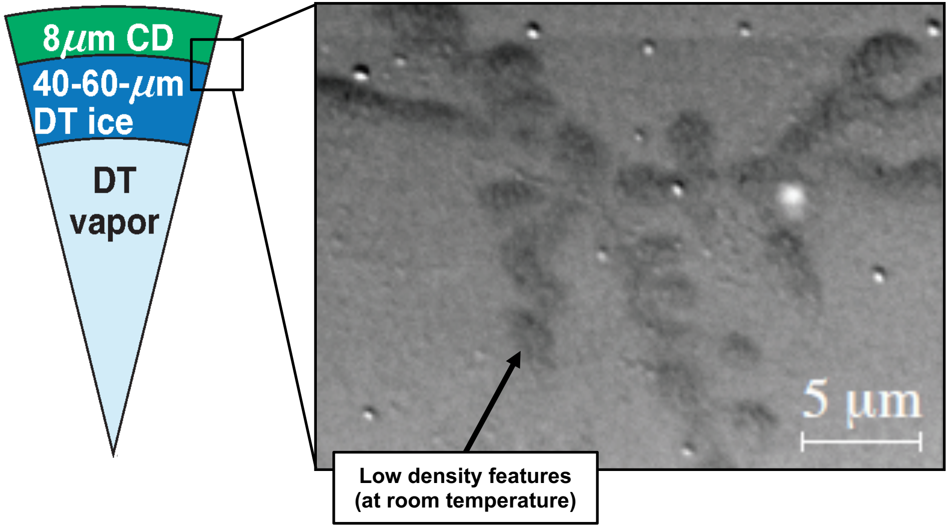
ICF target imperfections seed Rayleigh-Taylor instability growth and originate from multiple sources



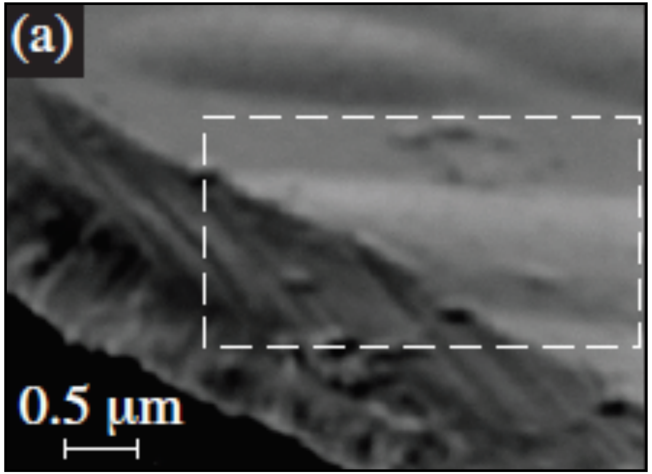
Radiation damage from tritium decay causes localized swelling and interfacial perturbations that seed instability growth

Electron micrograph of a permeation-filled shell[1]

Ablator surface at interface

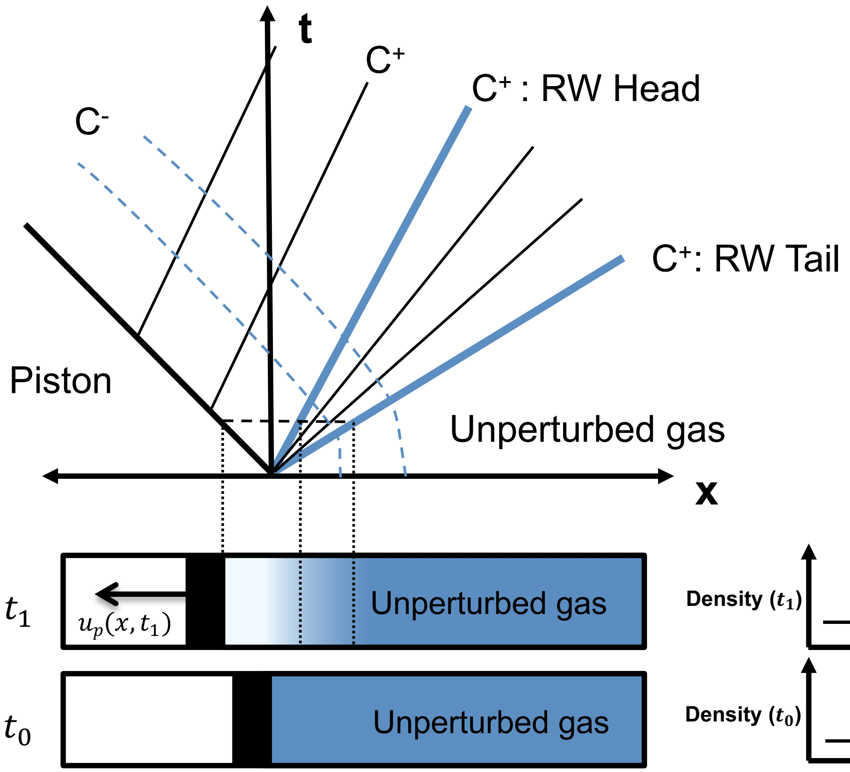


Cross section through feature



[1] D. R. Harding & W. T. Shmayda (2013) Stress- and Radiation-Induced Swelling in Plastic Capsules, Fusion Science and Technology, 63:2, 125-131

Characteristic lines describe the evolution of information in acoustic waves

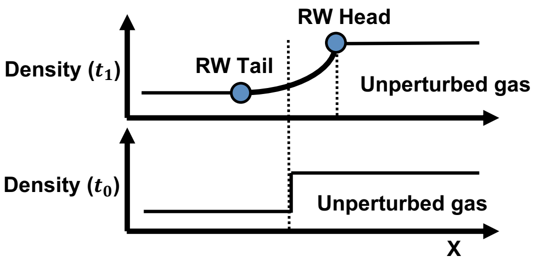


Characteristic Line Definition:

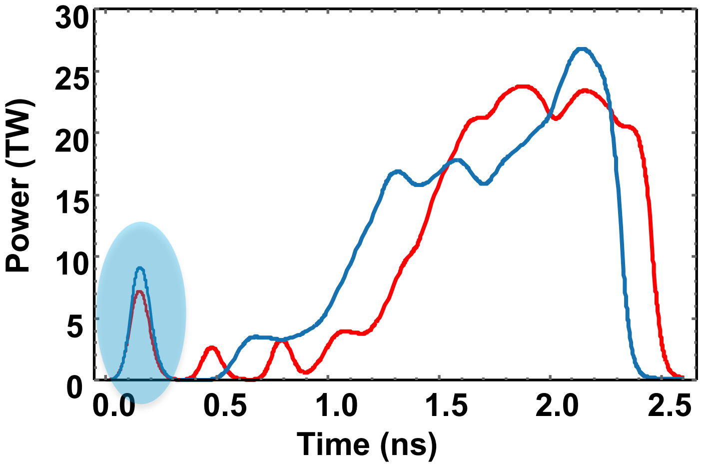
$$C^+ : \frac{dx^+}{dt} = U + c_s$$

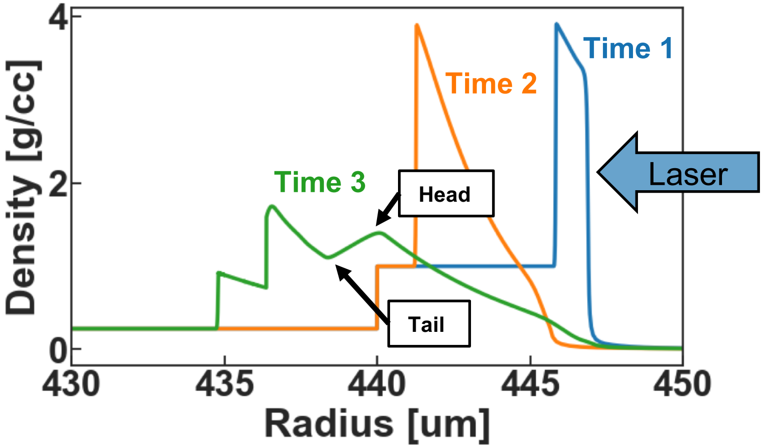
$$C^- : \frac{dx^-}{dt} = U - c_s$$

U: velocity
c_s: local sound speed



In unsupported shock designs, the ice-ablator interface creates a reflected rarefaction wave during the shell acceleration phase





This rarefaction wave travels through the relaxed density profile and generates converging characteristic lines near the tail

Perturbations traveling along convergent characteristic lines are amplified[1]

Conservation equation for $\tilde{v}$

$$\partial_t \tilde{v} + \partial_x [\tilde{v}(U \pm c_s)] = 0$$

Solution: $\tilde{v} = \underbrace{\tilde{v}_0\left(x e^{\int^t \Gamma\, \mathrm{dt}}\right)}_{\text{Initial perturbation shape}} e^{\int^t \Gamma\, \mathrm{dt}}$

Growth Rate: $\Gamma = -\partial_x (U \pm c_s)$

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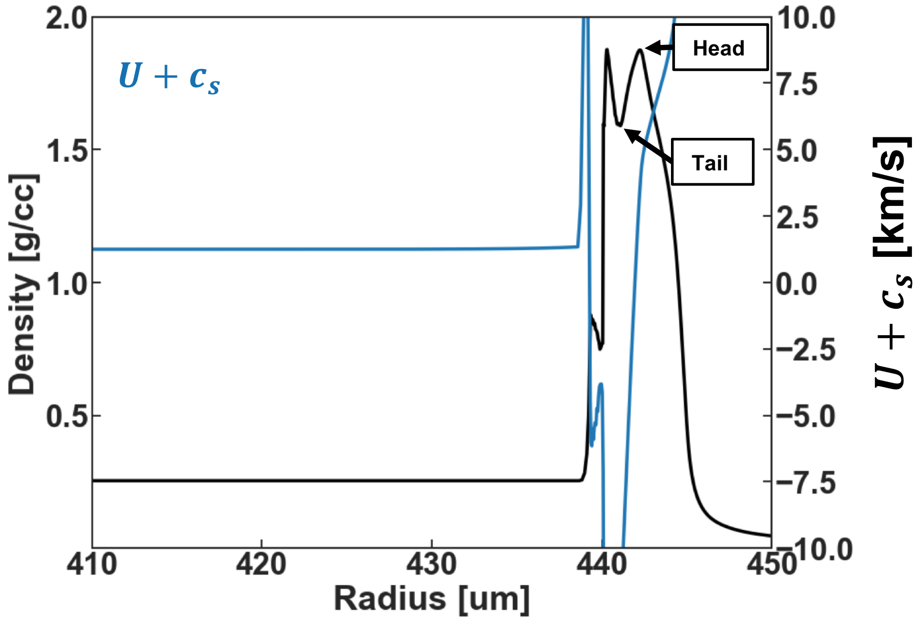

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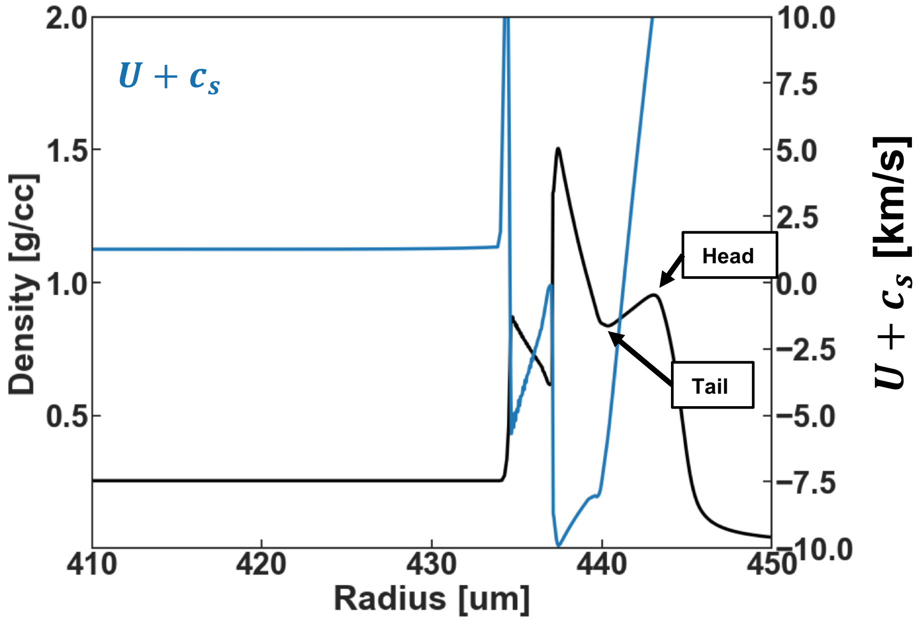

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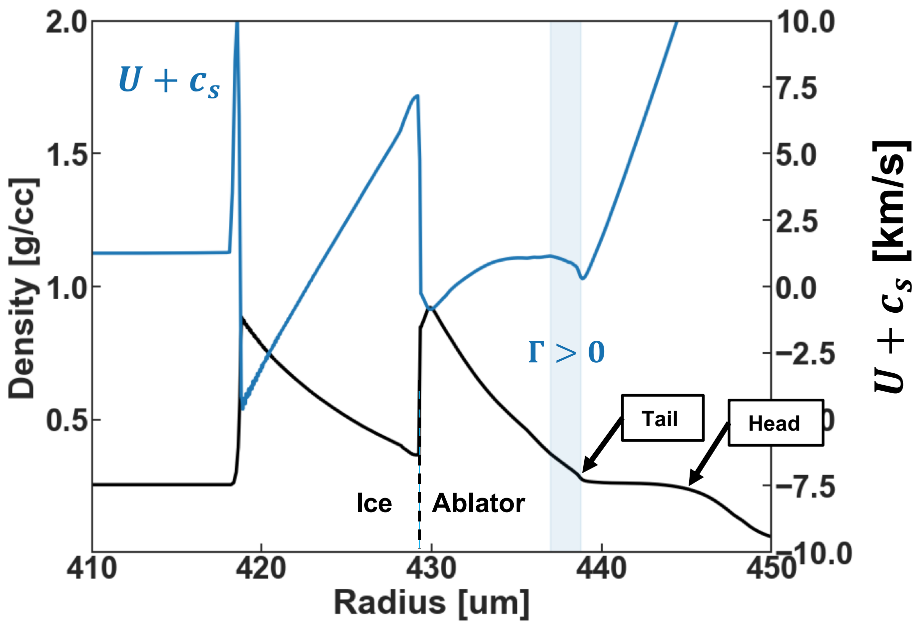

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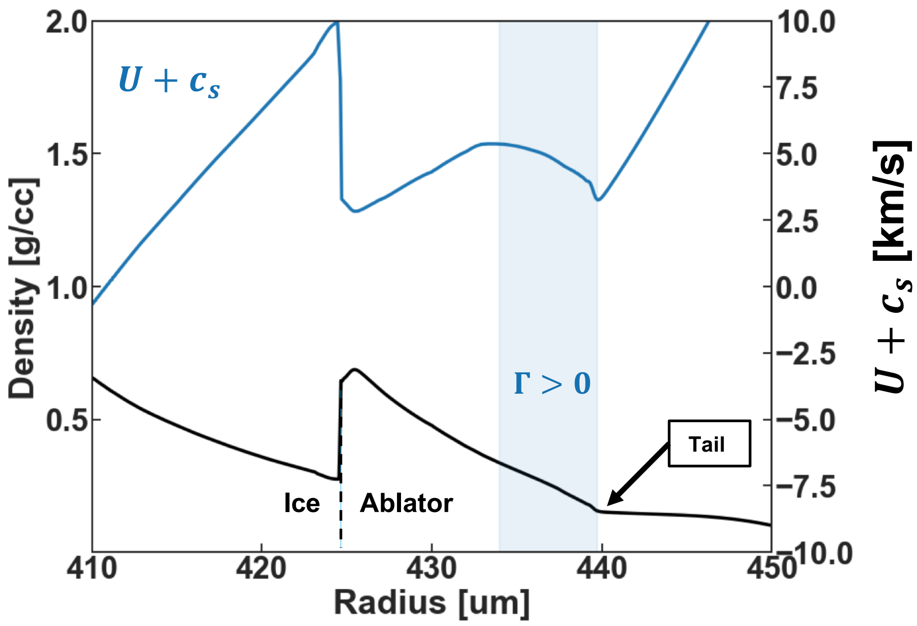

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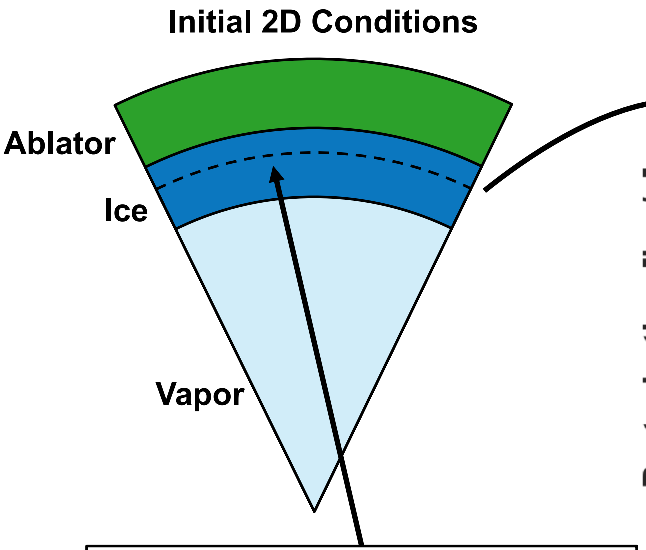
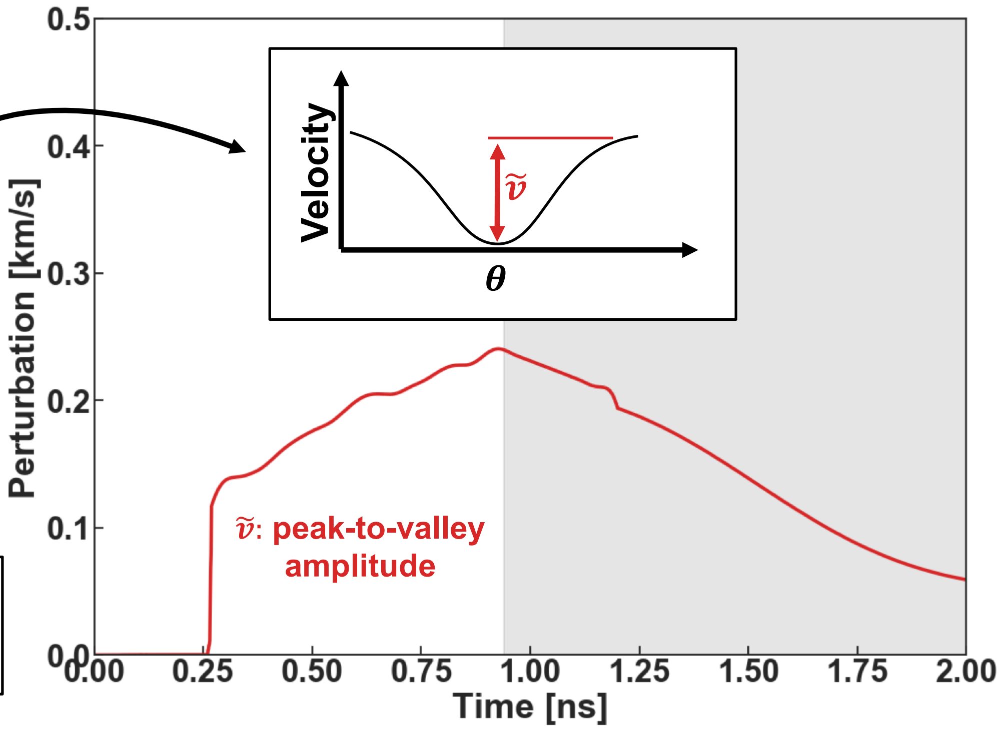
Multi-dimension hydrodynamic simulations captured overall profile behavior; however, perturbation amplification did not follow expected trends



ℓ-mode density perturbation at t_0

$$\tilde{\rho} = \rho_{ice} + \eta\rho_{ice}\cos\ell\theta$$

$$\{\eta \mid 0 \leq \eta \leq 1\}$$



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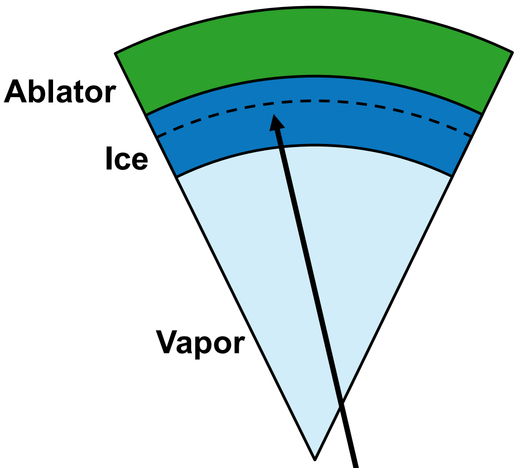
Initial 2D Conditions



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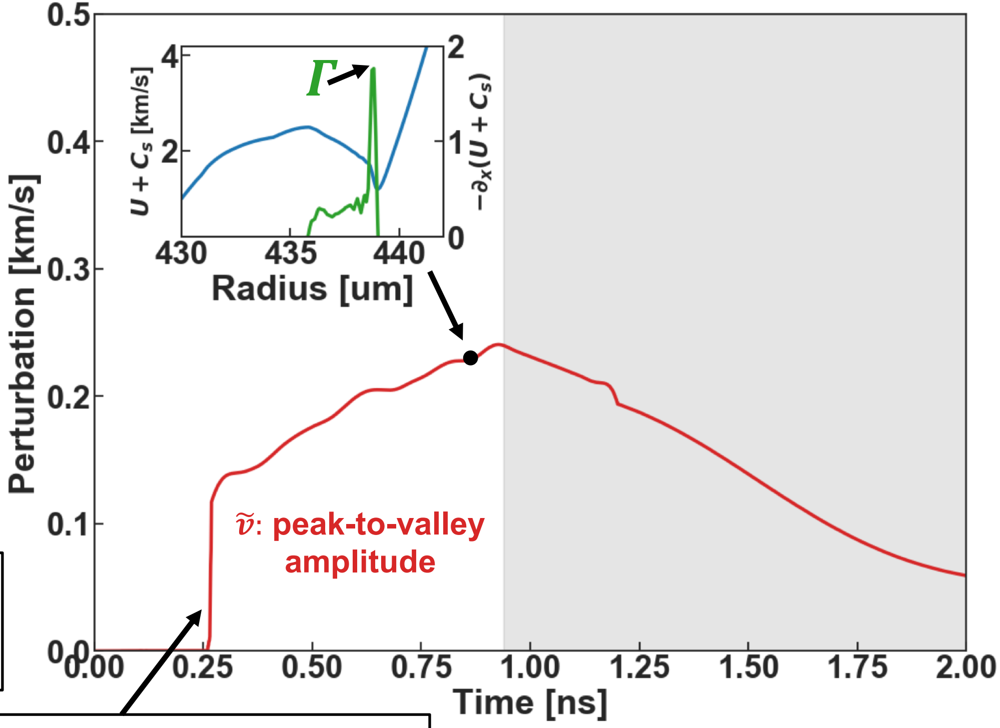

SW reaches ice perturbation

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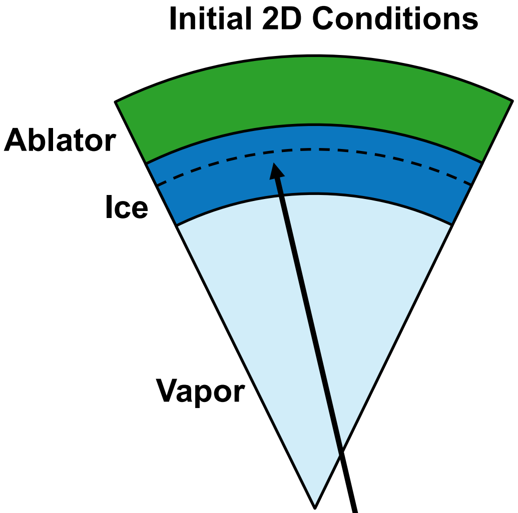

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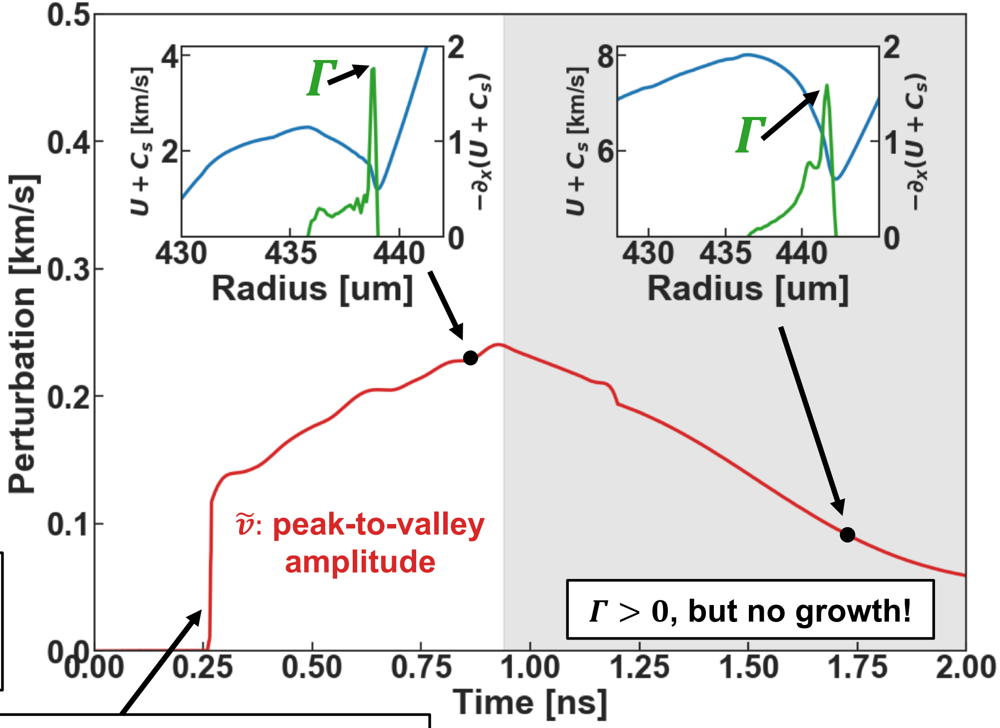
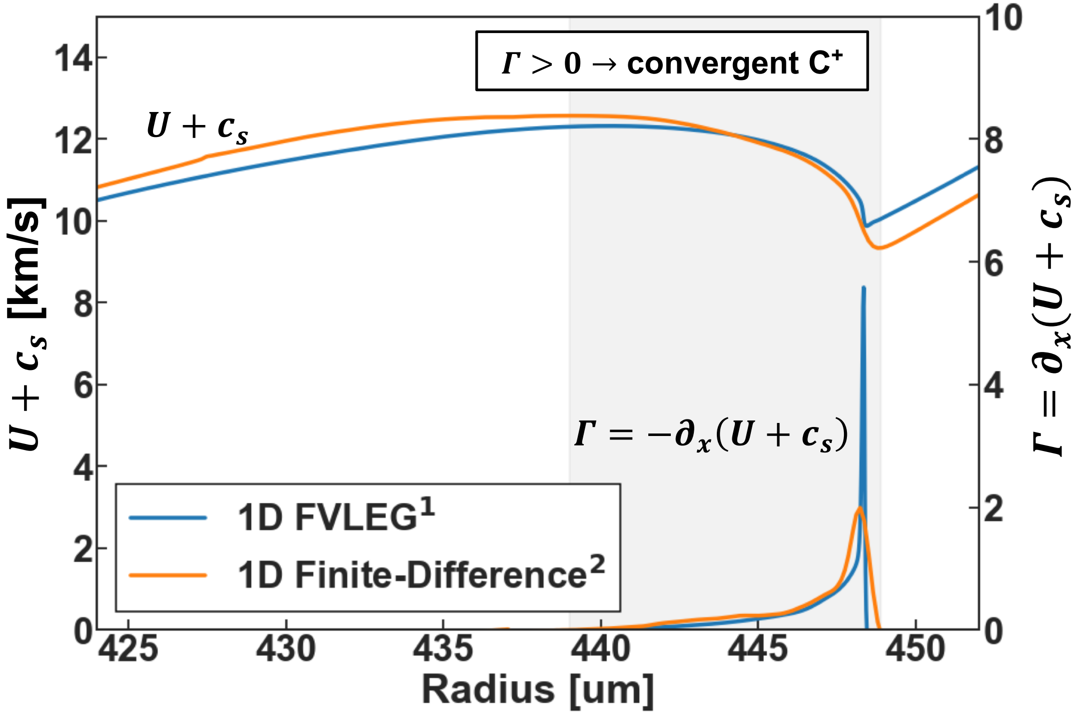


SW reaches ice perturbation

A simplified 1D survey compared simulations using two numerical schemes to understand velocity profile steepening and perturbation growth dynamics

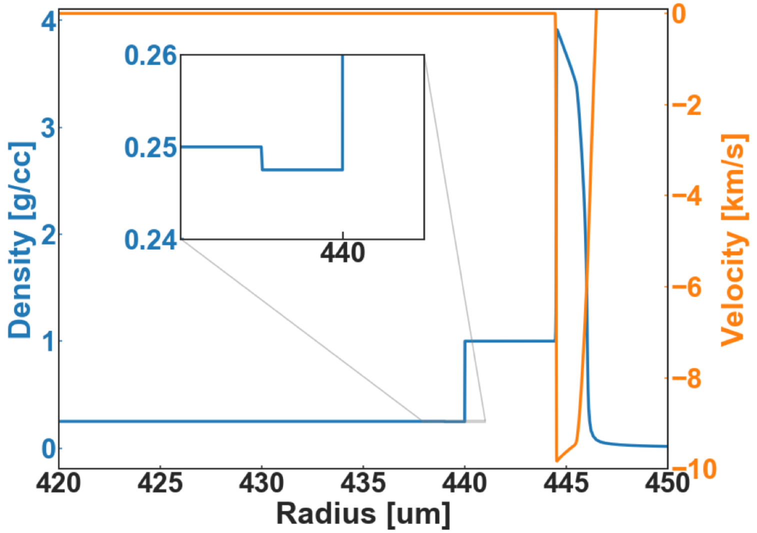


- This survey compared perturbation location, size, and grid resolution
- A scheme that explicitly incorporates characteristics is required to adequately capture steepening at the RW tail
  - e.g. Finite-Volume Local Evolution Galerkin (FVLEG)[1]

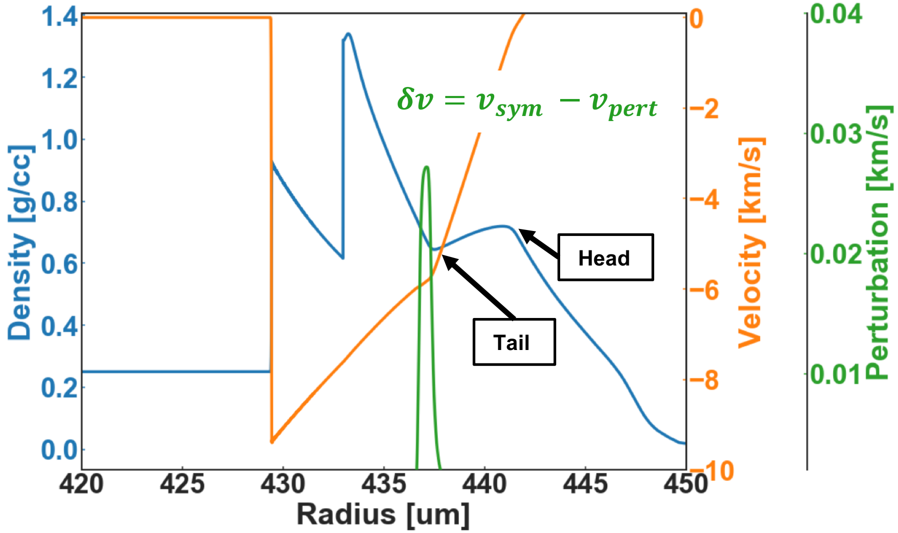
[1] Y. Sun, Y.X. Ren, J. Comp. Phys. 228 4945 (2009)
[2] J. Delettrez, et. al, Phys. Rev. A 36, 3926 (1987)

Profile distortions were then applied near the ice-ablator interface and tracked by the difference in velocity profiles at the rarefaction wave tail

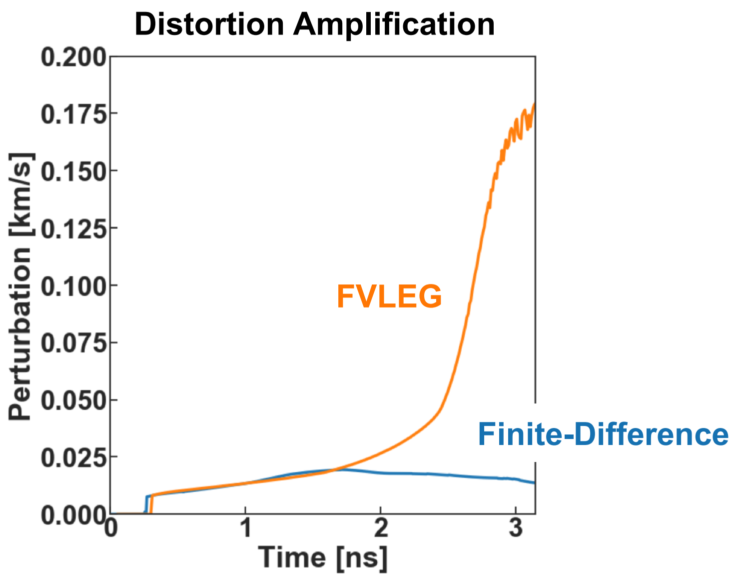
Pre-shock breakout

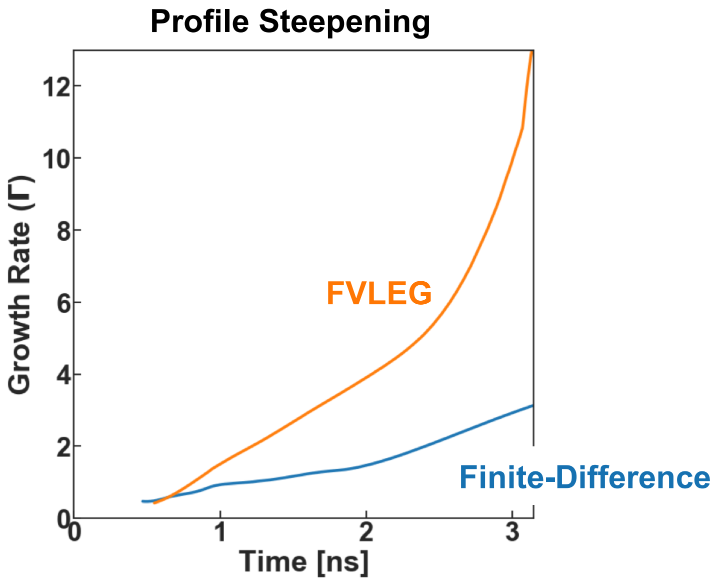


Post-shock breakout



Perturbation amplification is driven by how well steepening is captured at the tail of the rarefaction wave





FVLEG will be extended into multi-dimensions to capture perturbation growth

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