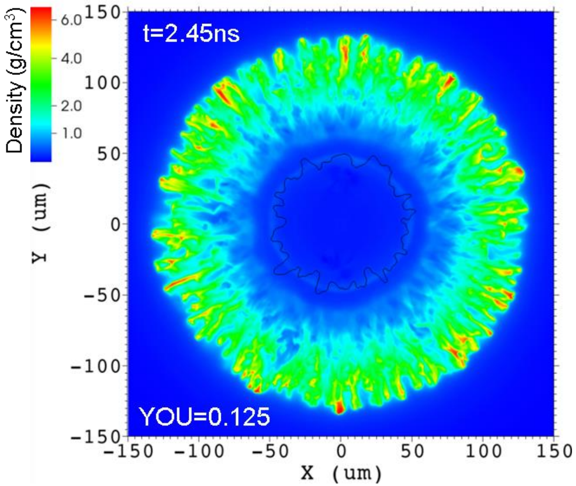
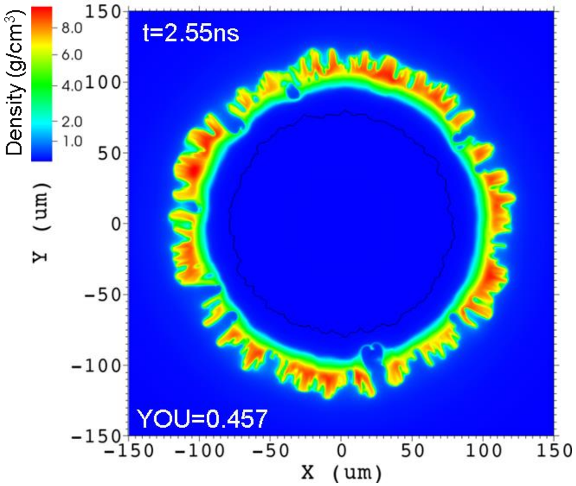
Mitigating Imprint in Direct-Drive Implosions Using Rarefaction Flows

3-D *ASTER* simulations of OMEGA cryogenic implosion designs with laser imprint

Design using supported shock



Design using unsupported shock



Targets at CR ~ 4

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Summary

Imprint in direct-drive implosions can be mitigated employing optimized picket pulses, which produce rarefaction post-shock flows

- Effects of imprint in OMEGA implosions were studied using the 3-D hydrodynamic code *ASTER*[1]
- Simulations show that the development of imprint modulations mainly depends on the type of flows developing inside compressed implosion shells
- Laser pulses with continuous drive launch supported shocks with almost uniform post-shock flows, which lead to enhanced short-scale ($\ell \sim 100$ to 200) imprint modulations
- Laser pulses with picket(s) launch unsupported shocks with rarefaction post-shock flows, in which sound waves convect imprint modulations outward,[2] consequently reducing effects of these modulations
- Optimized laser pulses with picket(s) are required to successfully mitigate imprint

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[1] I. V. Igumenshchev *et al*., Phys. Plasmas **23**, 052702 (2016).

[2] A. L. Velikovich *et al*., Phys. Plasmas **8**, 592 (2001).

Collaborators

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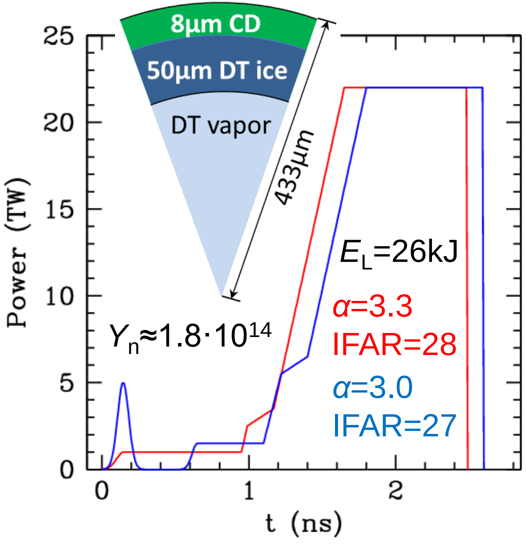
Reduction of imprint modulations in implosions driven by laser pulses with picket(s) has been observed in 2-D simulations for a long time[1]

- Suppression of the short-time RT growth of mass modulations because of presence of the fuel-ablator interface[1]
- Decay (or relaxation) shock produced by a picket pulse decreases γ_{RT} because of increasing the ablative stabilization ("adiabat shaping")[2 - 4]
- Modern numerical simulations, with advances of including the third dimension and using higher spatial resolution, make it possible to reveal another important mechanism of imprint mitigation

[1] T.J.B. Collins and S. Skupsky, Phys. Plasmas **9**, 275 (2002).
[2] V. N. Goncharov *et al*., Phys. Plasmas **10**, 1906 (2003).
[3] K. Anderson and R. Betti, Phys. Plasmas **11**, 5 (2004).
[4] T.J.B. Collins *et al*., Phys. Plasmas **11**, 1569 (2004).

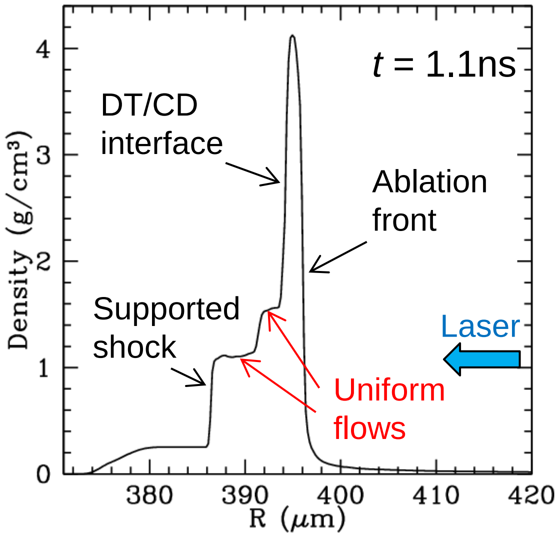
Picketless and picket pulses produce different type flows inside compressed implosion shells

Two cryogenic implosion designs

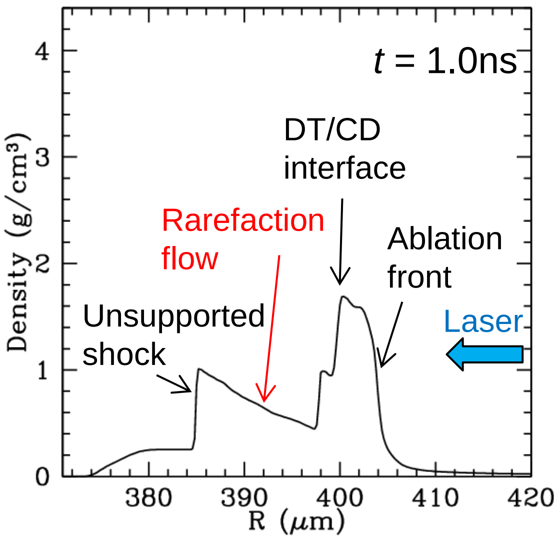


Simulated radial density profiles

Picketless pulse design



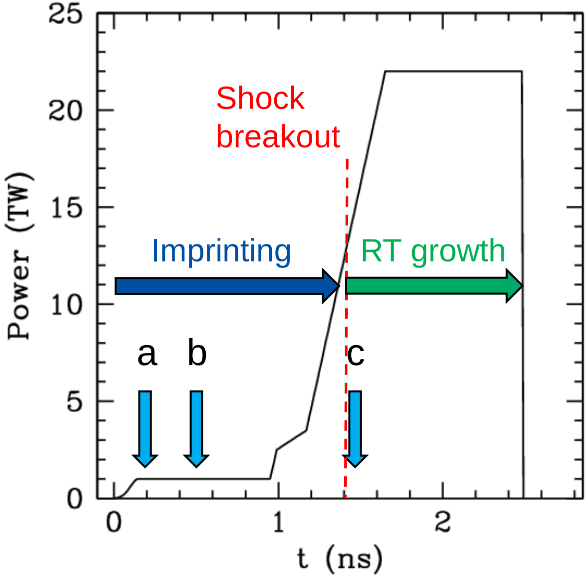
Single-picket pulse design



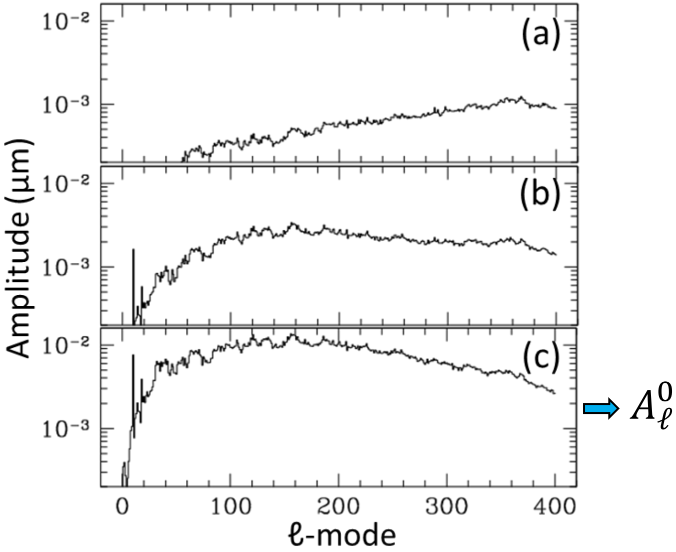
- The evolution of imprint modulations depends on the type of post-shock flows

Supported shocks lead to enhanced imprint modulations

Picketless laser pulse



Evolution of the ρR spectrum



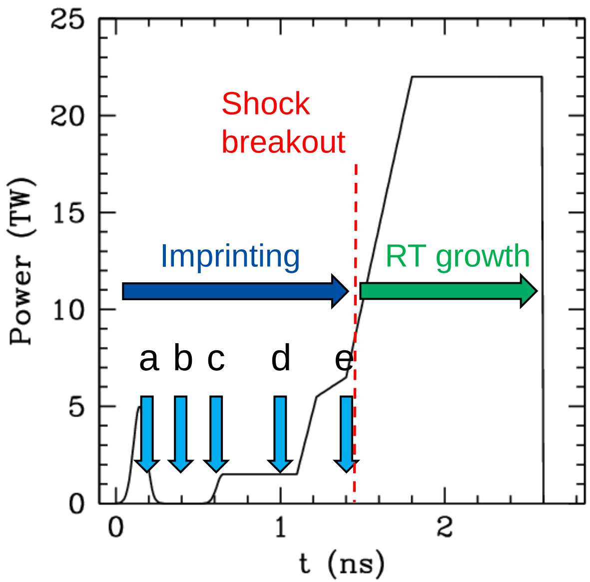
- High ℓ modes grow as predicted by Goncharov's imprint model*
- Modes with ℓ ~100 to 200 grow most efficiently and become dominant by the end of imprinting phase
- These modes are efficiently amplified by the RT growth

$$A_\ell(t) = A_\ell^0 \cdot \exp(\gamma_{\mathrm{RT}} t)$$

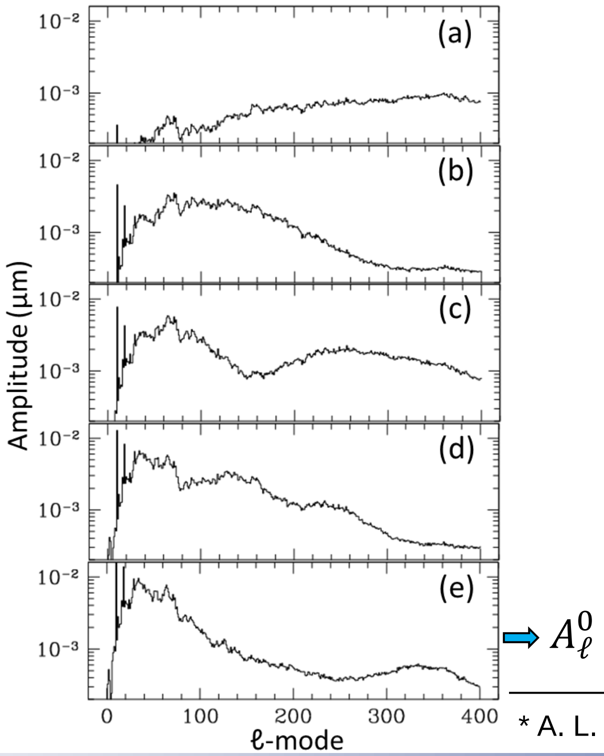
* V. N. Goncharov *et al*., Phys. Plasmas **7**, 2062 (2000).

Unsupported shocks and following rarefaction flows result in decay of short-wavelength imprint modulations

Single-picket laser pulse



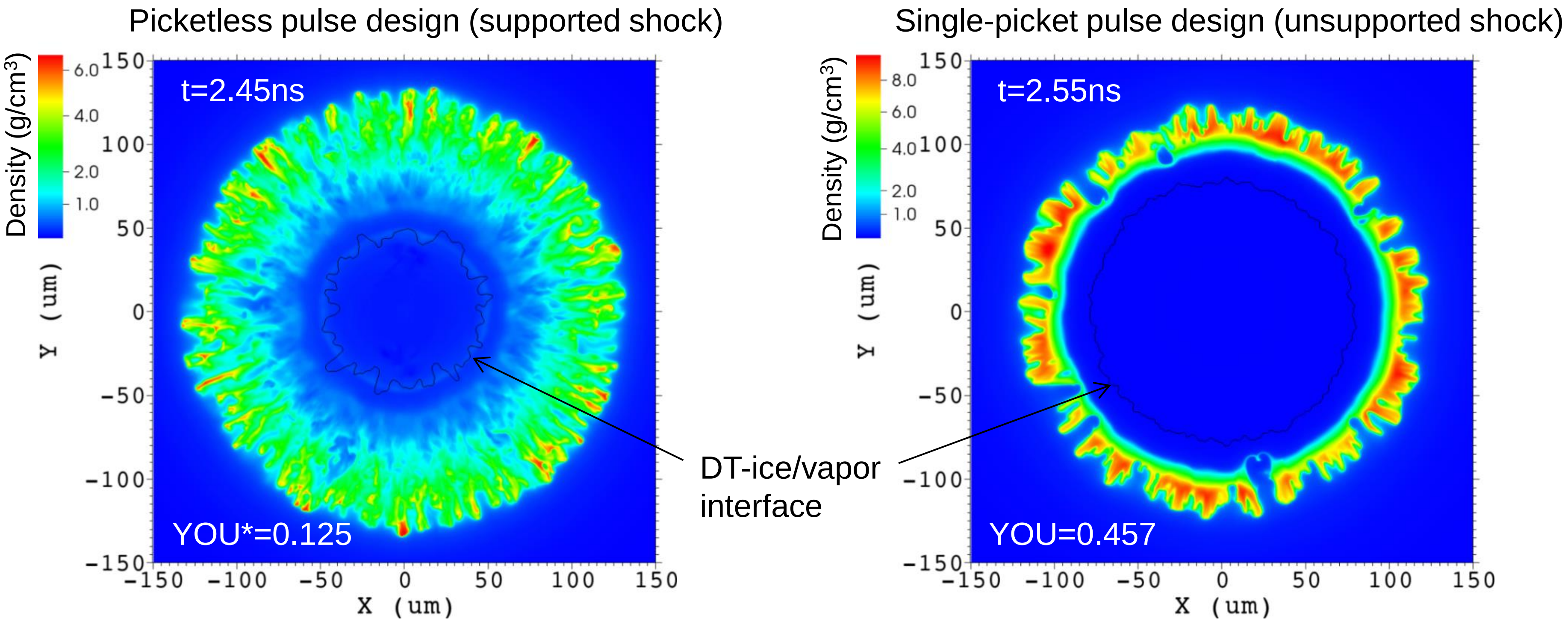
Evolution of the ρR spectrum



- Imprint modes experience phase inversion, which are caused by decaying areal mass oscillations*
- This phase inversion results in suppression of high ℓ modes
- The spectrum at the end of imprinting phase is dominated by modes with ℓ ~ 30
- Modes with ℓ < 30 are hydro-dynamically decoupled and not affected by the RT growth during the acceleration phase

* A. L. Velikovich et al., Phys. Rev. E **72**, 046306 (2005).

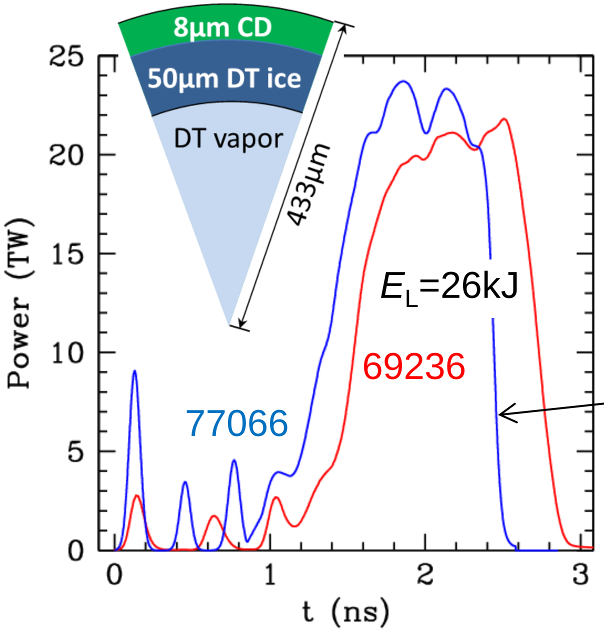
The shell compressed by the unsupported shock shows much less damages because of imprinting



* YOU is the neutron yield over the yield in uniform (1-D) simulations

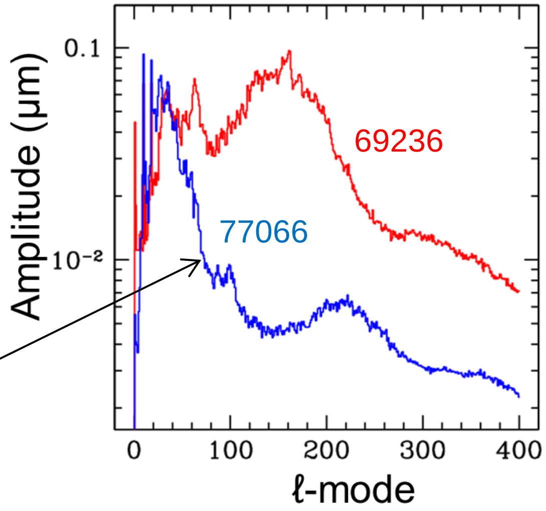
Efficient imprint mitigation strategy requires an optimization of picket pulses

Target and pulse shapes for shots 69236 and 77066



Optimum imprint mitigation

Spectrum of ρR modulations at $R_{shell} \approx 300\mu m$ (beginning of acceleration)

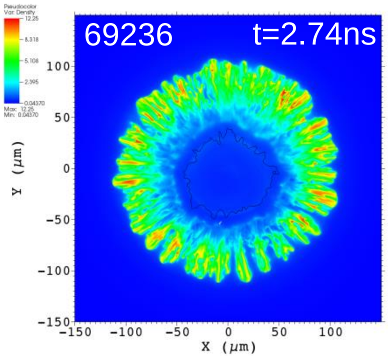


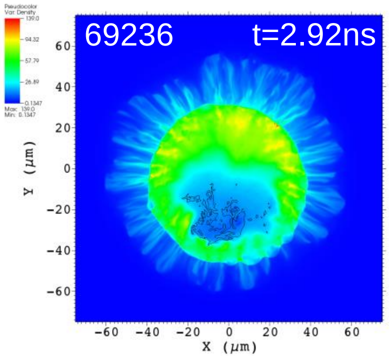
69236 (α=2)	Dominant ℓ modes ~ 150
77066 (α=3)	Dominant ℓ modes ~ 30

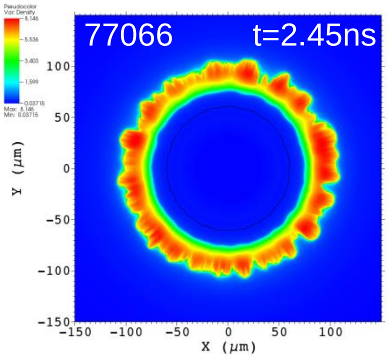
The difference in performance of shots 69236 and 77066 is reproduced by *ASTER* simulations

$R_{shell} \approx 100 \mu m$

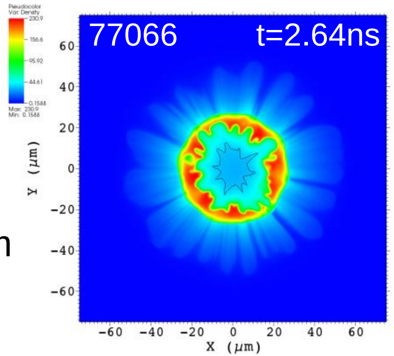
Neutron peak







Optimum



	69236 ($\alpha = 2$)	77066 ($\alpha = 3$)
Y_{exp}	$(1.08 \pm 0.05) \times 10^{13}$	$(3.93 \pm 0.2) \times 10^{13}$
$Y_{1\text{-}D}$	1.89×10^{14}	1.35×10^{14}
$Y_{3\text{-}D}$	1.23×10^{13}	9.79×10^{13}

- Imprint is predicted to be a dominant performance degradation mechanism in shot 69236

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