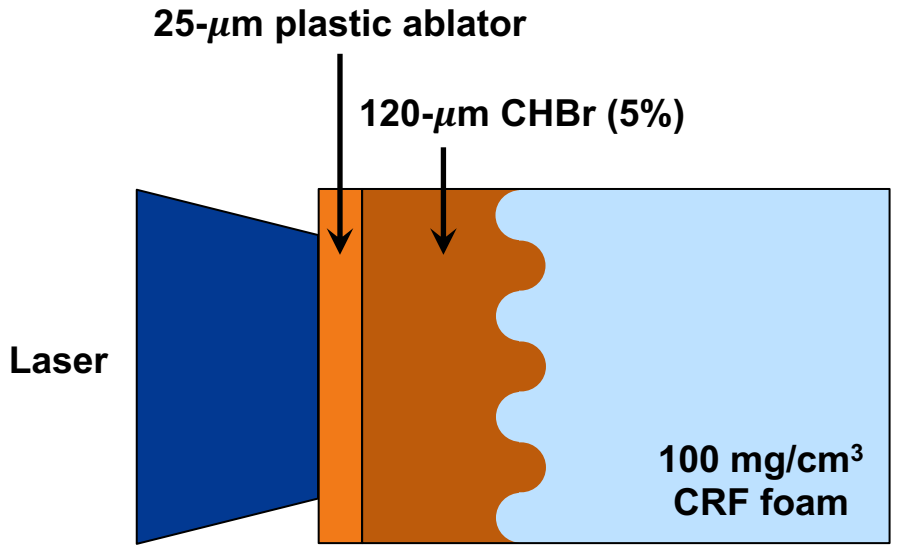
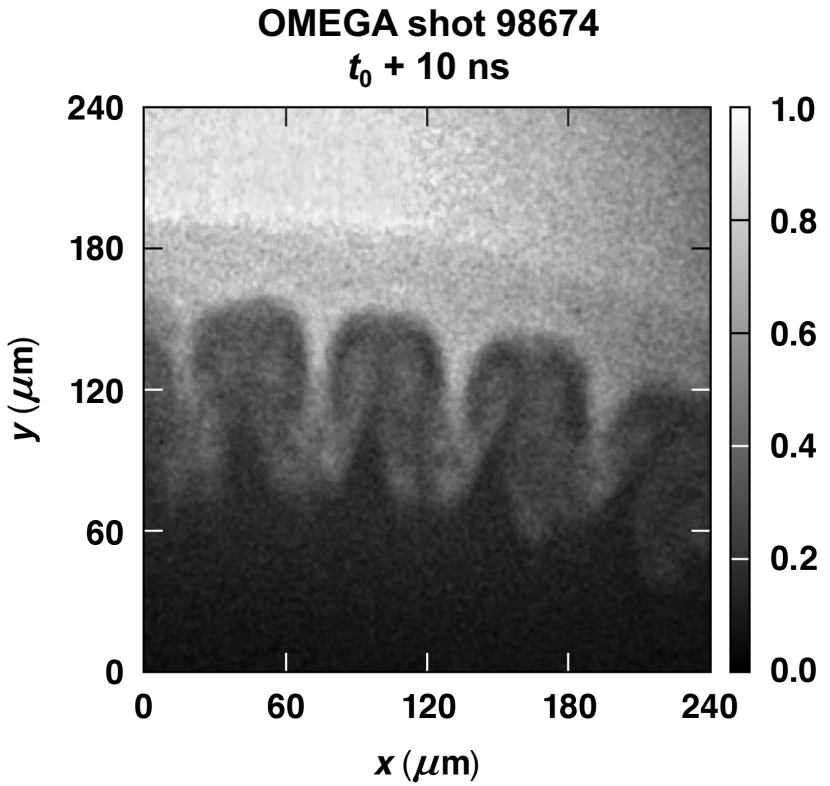
Imaging of Hydrodynamic Perturbation Evolution Using a Fresnel Zone Plate





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62nd Meeting of the
American Physical Society
Division of Plasma Physics
9–13 November 2020

Summary

Under high-energy-density conditions, x-ray radiography of hydrodynamic perturbation evolution is improved using Fresnel zone plates

- Resolution tests using a zone plate and a 4.75-keV Ti He-like resonance line have achieved 1-μm resolution using direct x-ray detection with a CCD
- Radiographs are obtained of single-mode perturbation evolution at a shock-driven interface between a plastic pusher and a low-density foam
- The radiographs show clear bubble and spike growth and asymmetric rollup

CCD: charge-coupled device

Collaborators

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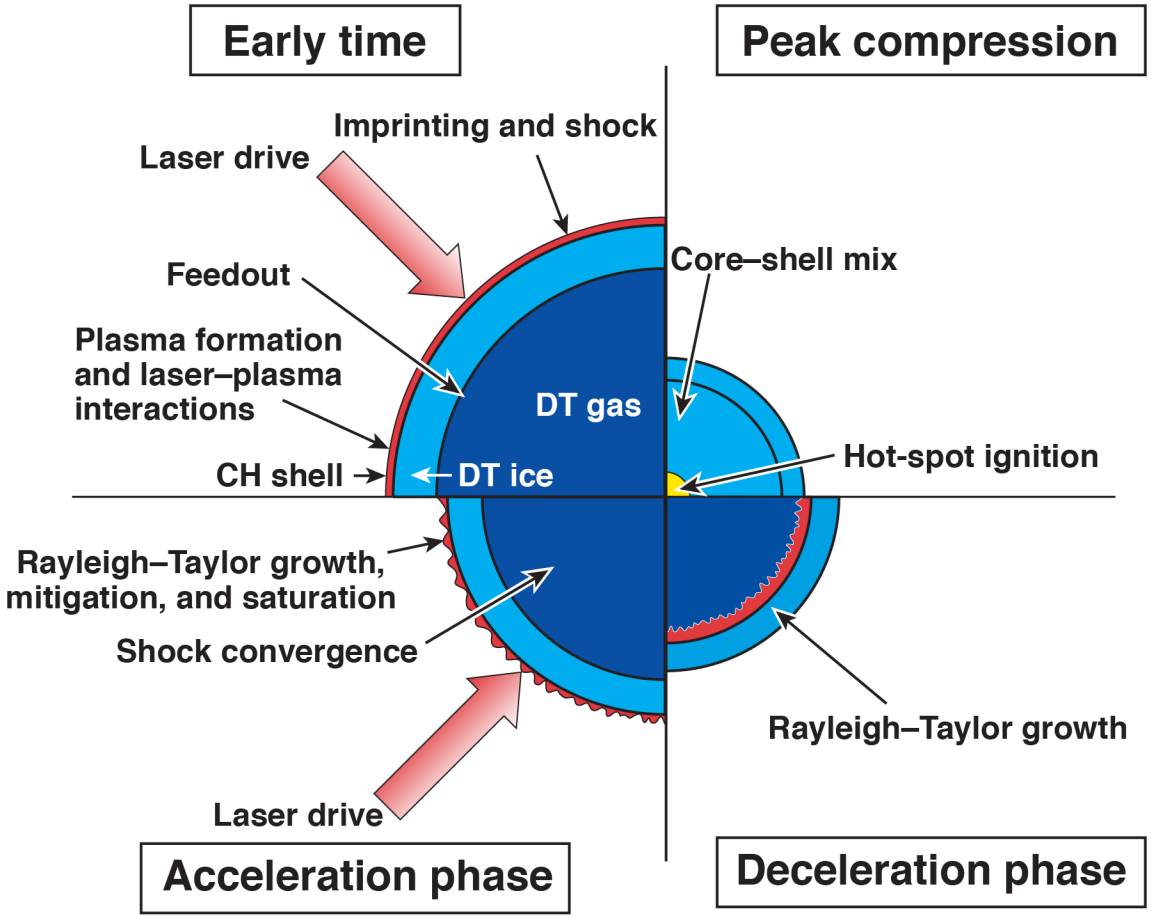
Motivation

The understanding of inertial fusion and many high-energy-density phenomena is challenged by hydrodynamic perturbation evolution at the micron scale

- Many factors affect ICF implosions
  - drive nonuniformity and implosion shape
  - engineering features and capsule defects
  - instability growth and mix
- Seed perturbation amplification is often required before x-ray imaging can resolve their presence
  - limits information about the system
  - motivates x-ray optic development

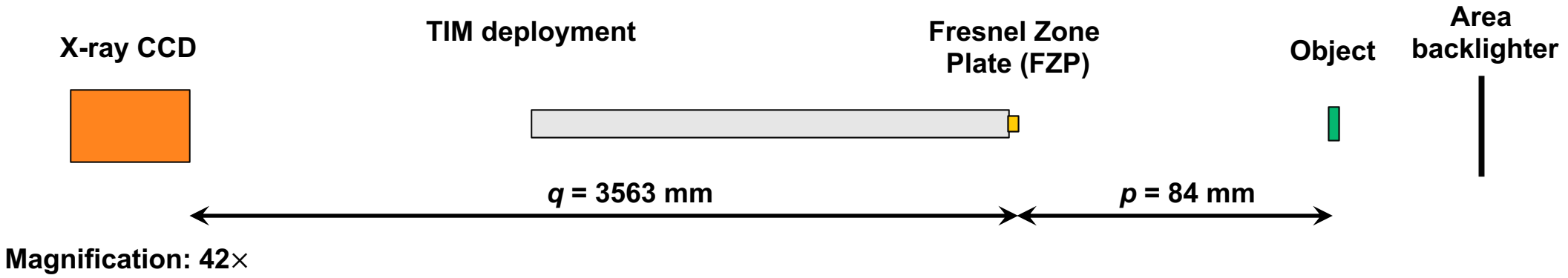
Zone-plate–based x-ray radiography provides a route to micron-scale spatial resolution.



ICF: inertial confinement fusion

A. V. Baez, J. Opt. Soc. Am. 51, 405 (1961).
A. Do *et al.*, Rev. Sci. Instrum. 89, 10G122 (2018).
K. Matsuo *et al.*, High Energy Density Phys. 36, 100837 (2020).

The OMEGA radiography platform couples a laser-driven area backlighter to a high-magnification zone plate optic and an x-ray CCD

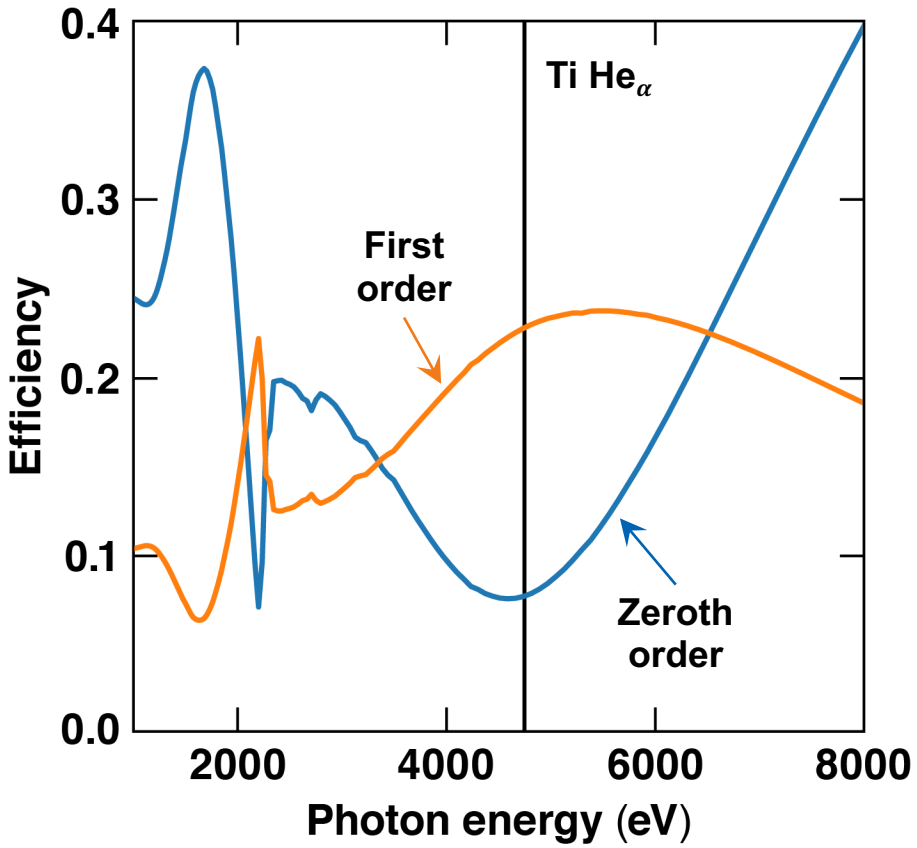


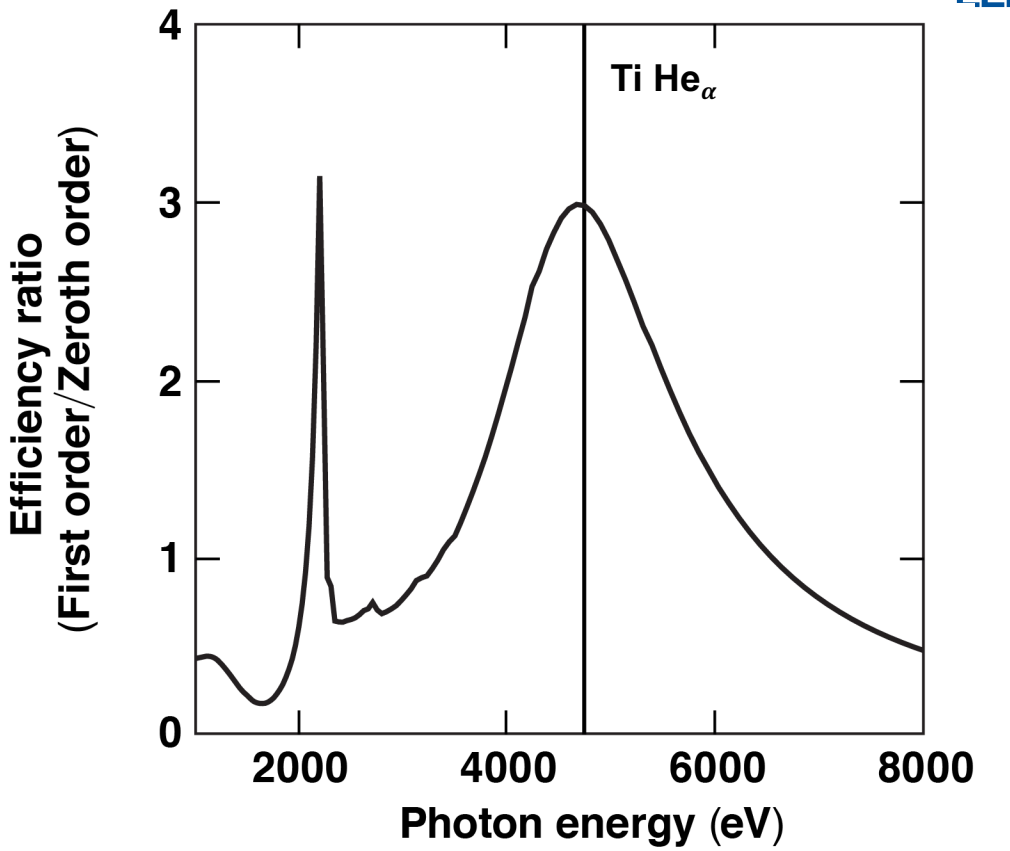
- Fresnel zone plate (FZP) focus equation: $\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$
- For an FZP, the focus is given by: $f_{\mathrm{FZP}} = \frac{4N(\Delta r)^2}{\lambda}$

p = object to optic distance
q = optic to image distance
N = number of zones
Δr = width of outermost zone of FZP
λ = wavelength of x rays

The zone plate deployment is set by the x-ray energy, the zone plate characteristics, and the focus equation.

The imaging system is optimized for 4.75-keV Ti He-like resonance line emission



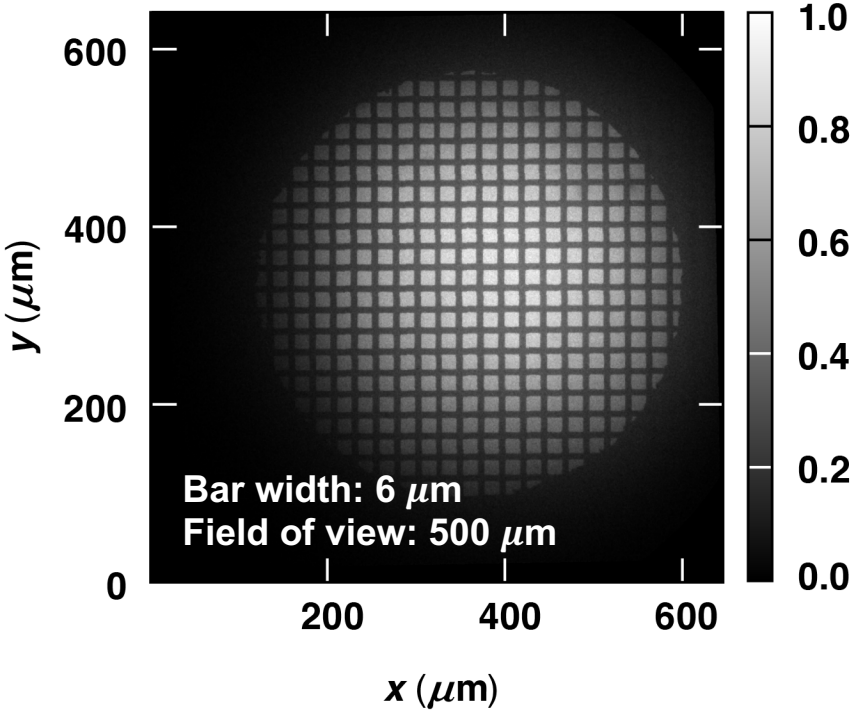


- Number of zones: 467
- Outermost zone width: 107 nm
- Au zone thickness: 850 nm

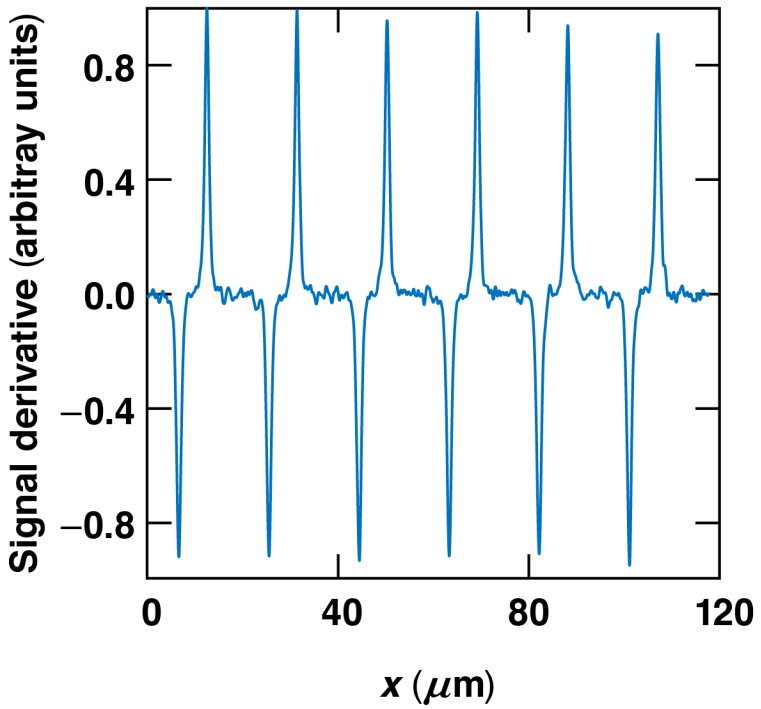
The efficiencies are calculated from atomic scattering factors.

At 42× magnification, a star resolution pattern shows 1-μm spatial resolution

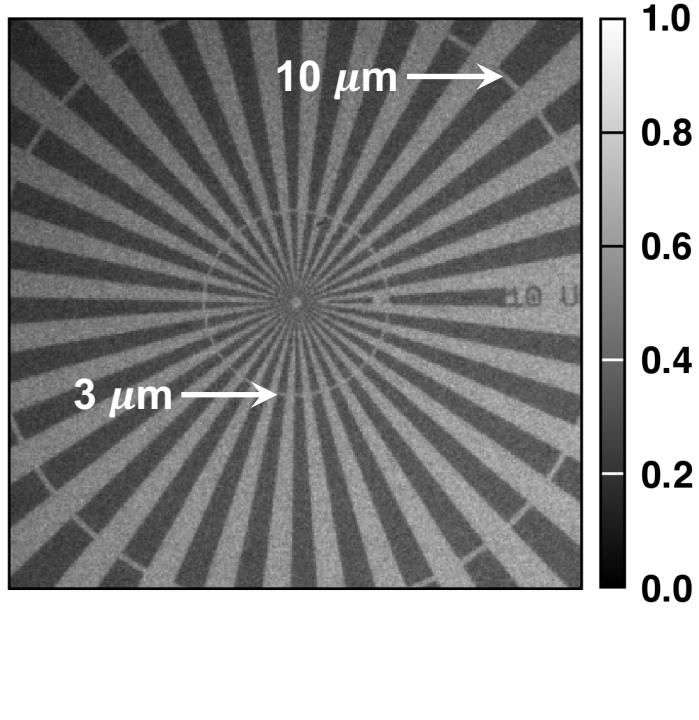
OMEGA shot 98669
Ti He$_\alpha$ source: 4.75 keV, 100 ps



Line spread function

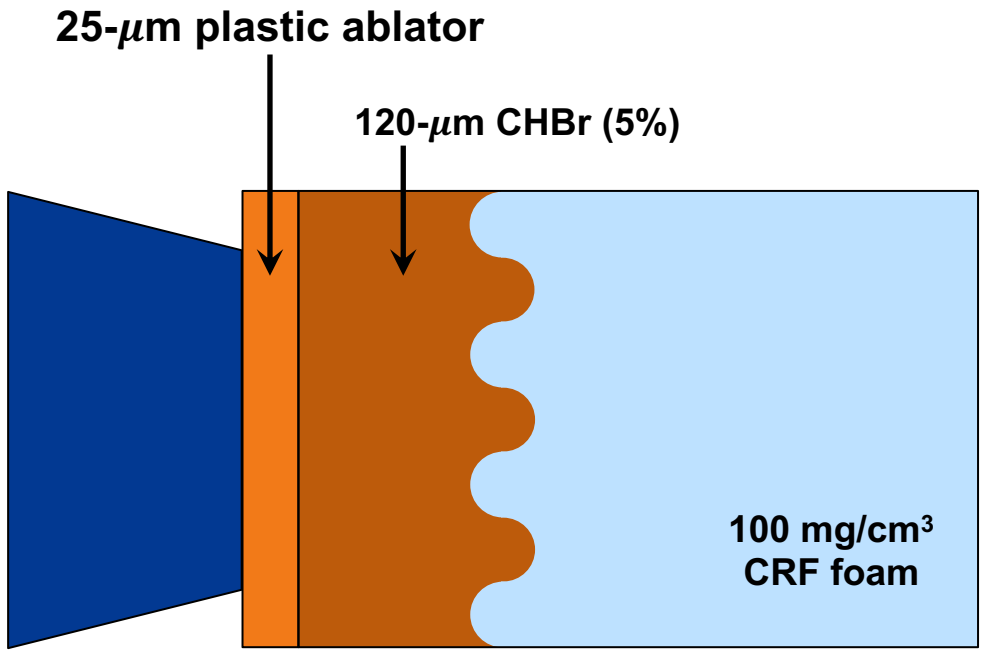


OMEGA shot 98670
Custom star pattern



Spatial resolution: (1.0±0.1) μm.

Imaging trials are carried out using single-mode perturbation evolution at an embedded interface following the passage of an unsupported shock wave

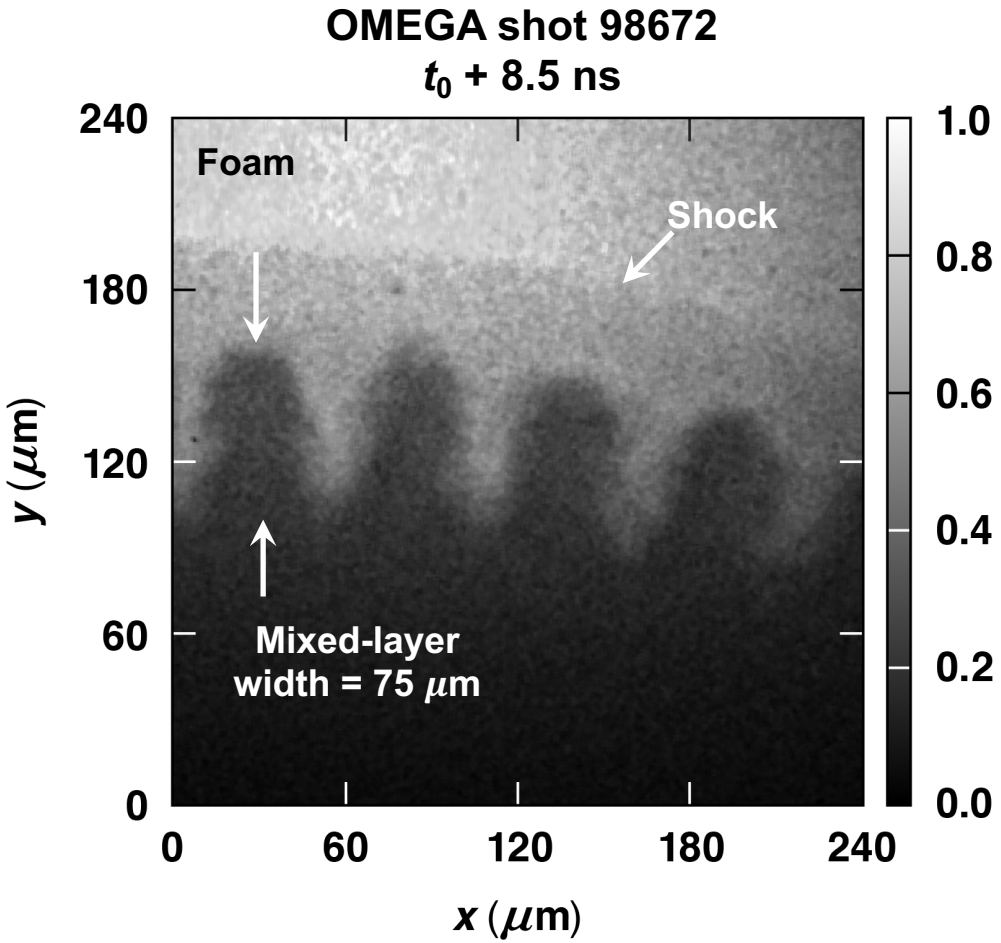


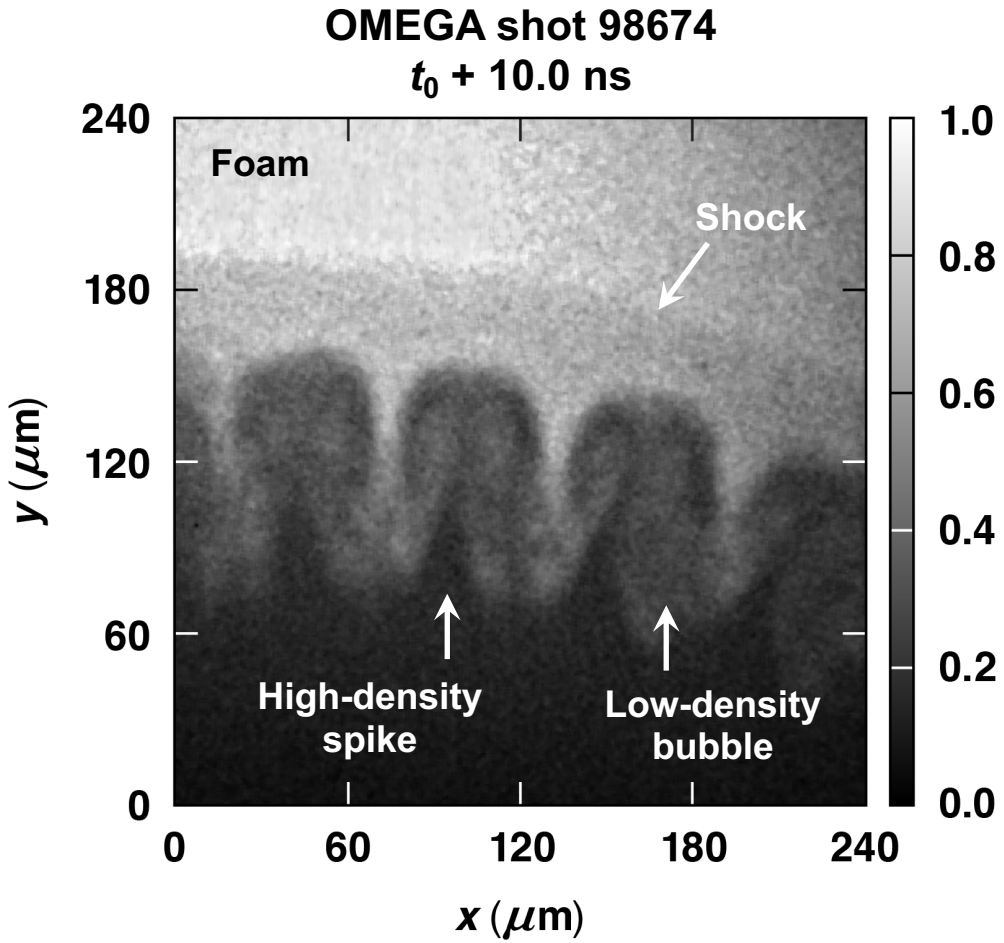
Laser drive

- 2.25-kJ, 1-ns pulse
- 7×10^{14} W/cm^2

- Initial modulation wavelength: 50 μm
- Peak-to-valley amplitude: 5 or 10 μm

The effects of vorticity generation, hydrodynamic expansion, and nonlinear Rayleigh–Taylor growth are observed in the radiographs at later times





Initial peak-to-valley amplitude: 5 μm.

Initial peak-to-valley amplitude: 10 μm.

Summary/Conclusions

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Data comparison with radiation hydrodynamic model predictions is the next step.

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