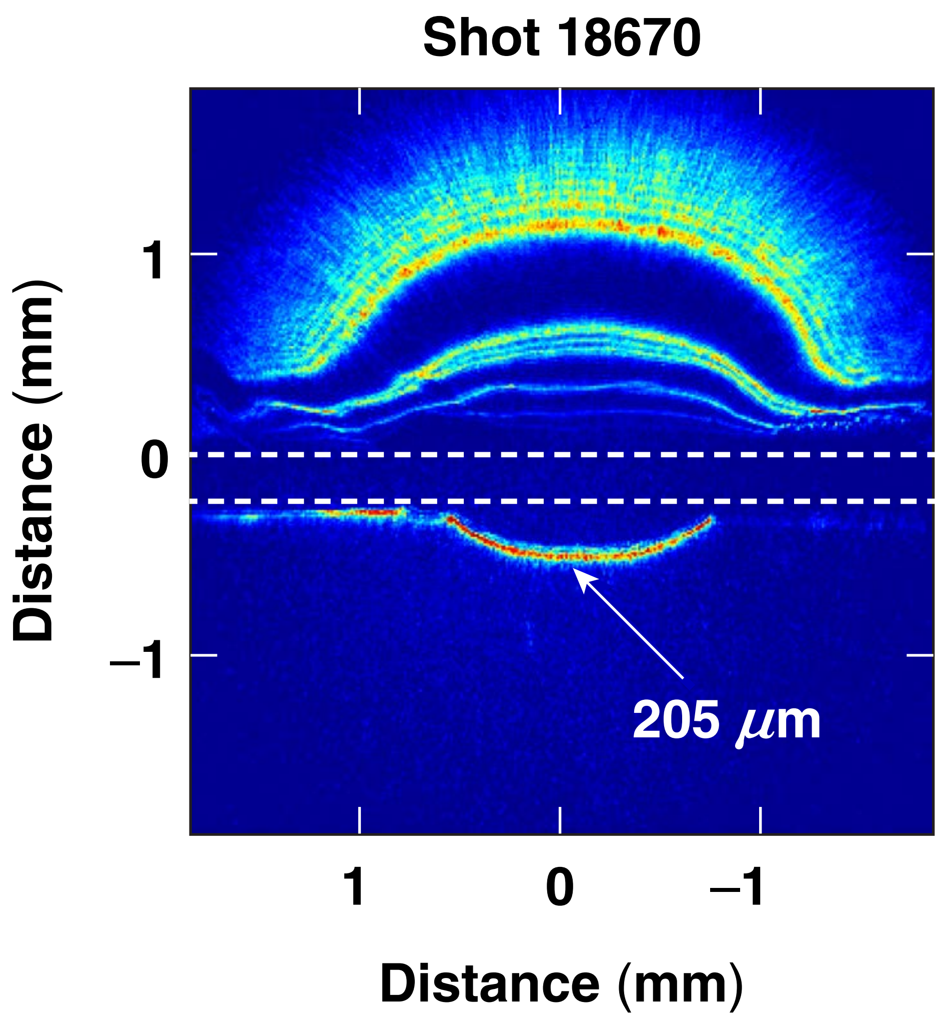
Probing the Release of Shocked Material



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Summary

Optical probing is used to characterize the release of shocked materials into vacuum

- National Ignition Facility (NIF) shock-timing measurements revealed inconsistencies in the predicted release of the ablator into the deuterium fuel
- Angular filter refractometry (AFR) imaging provided a measurement of release velocities and density-gradient scale lengths of the released material
- The spatial density profile for the shock-released state is very steep with an exponential scale length of $\lesssim 35\ \mu$m
- The entire diagnostic system was simulated in *FRED* and an analytic release density profile was used to create a synthetic AFR image

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Collaborators

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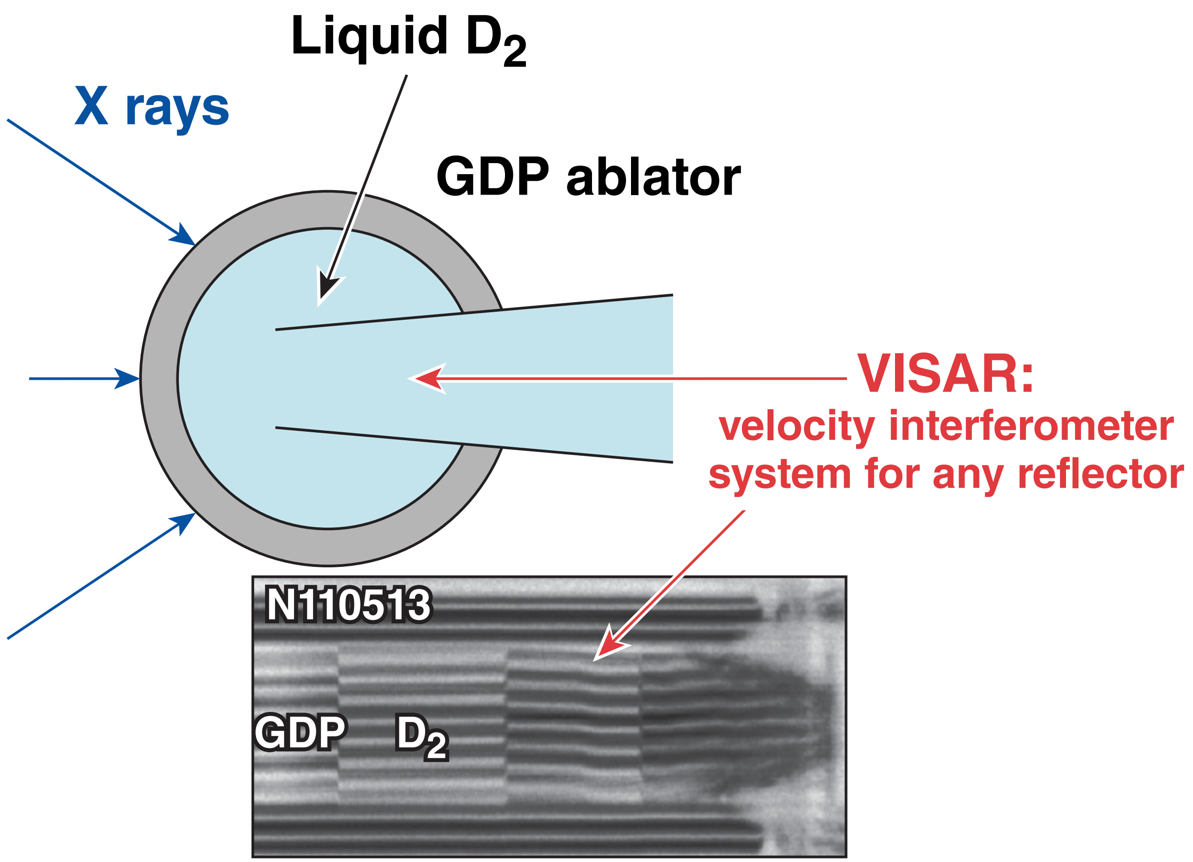
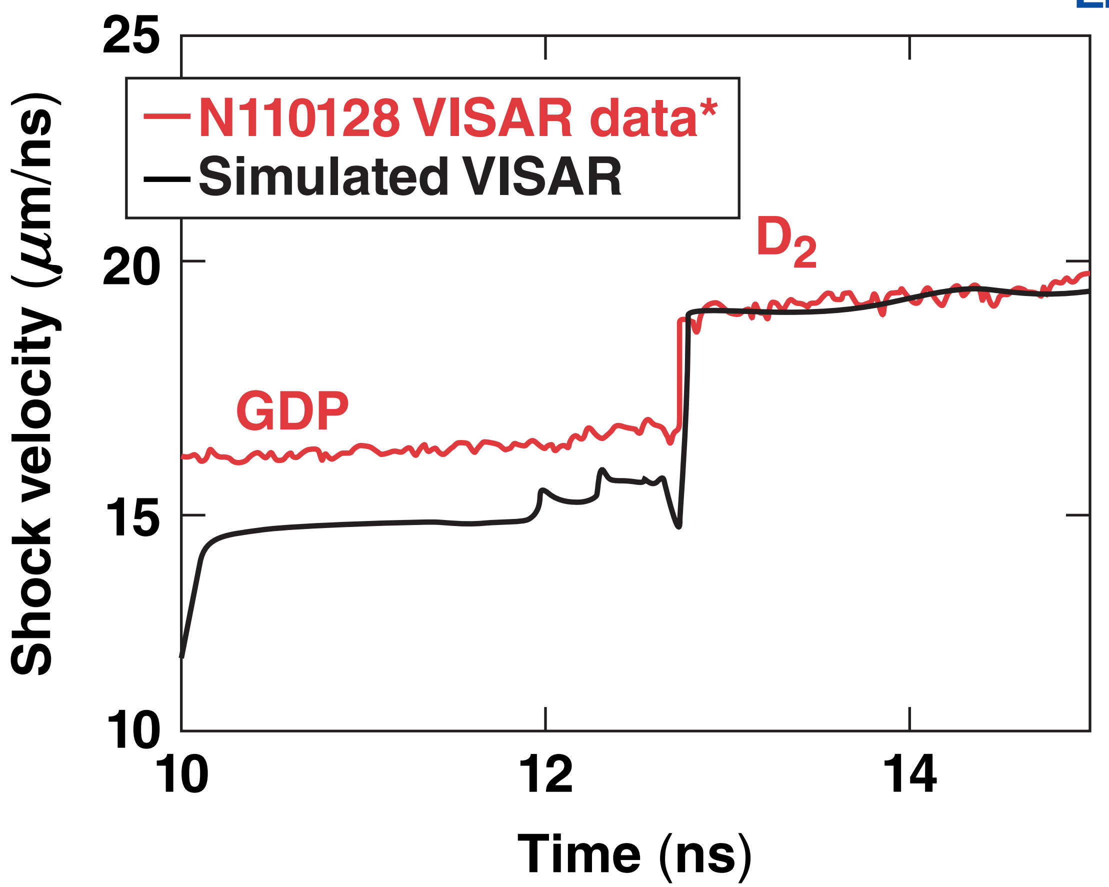
Motivation

Initial NIF shock-timing experiments revealed inaccuracies in the ablator release model





The glow-discharge polymer (GDP) equation-of-state model was corrected using release data into liquid D_2.**

*H. F. Robey *et al*., Phys. Plasmas 19, 042706 (2012).
**S. Hamel *et al*., Phys. Rev. B 86, 094113 (2012).

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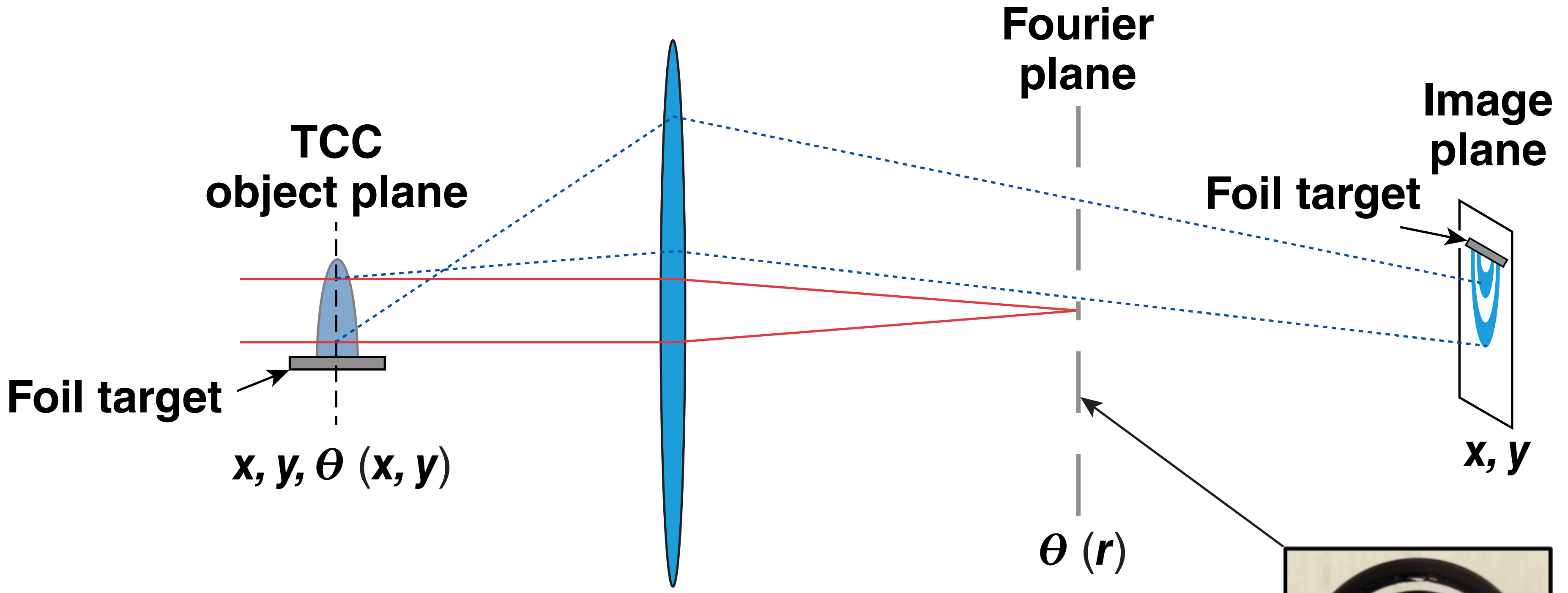
AFR maps the refraction angle of the probe beam at target chamber center (TCC) to contours in the image plane



AFR is a schlieren-type imaging with rings that calibrate the refraction angle.

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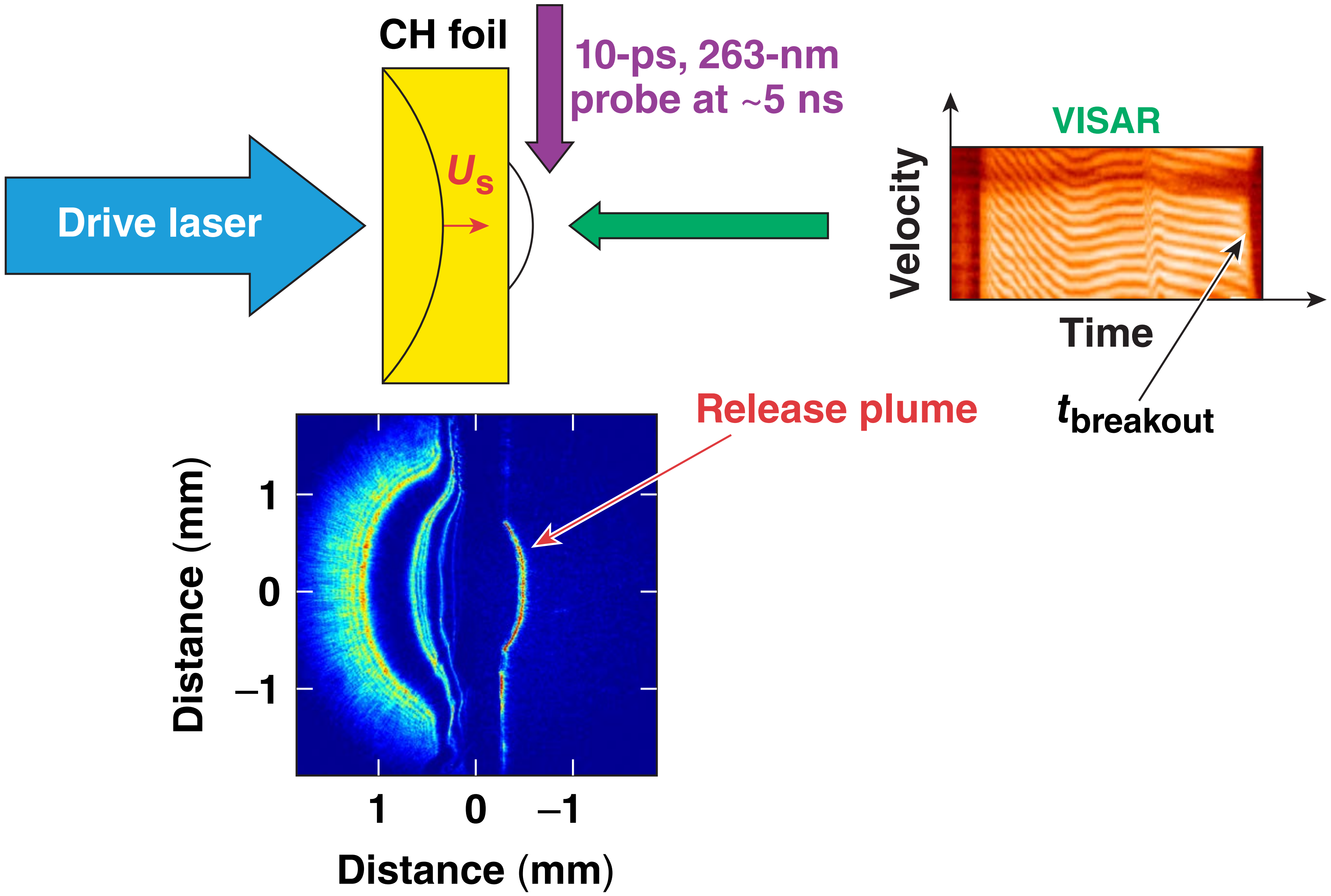
D. Haberberger *et al*., Phys. Plasmas 21, 056304 (2014).

A UV beam probed the release plumes of shocked materials and VISAR provided the initial conditions



Shot 18670
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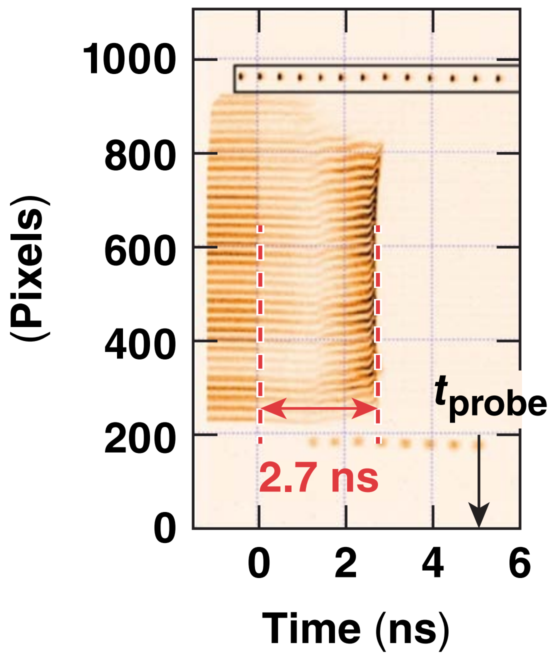
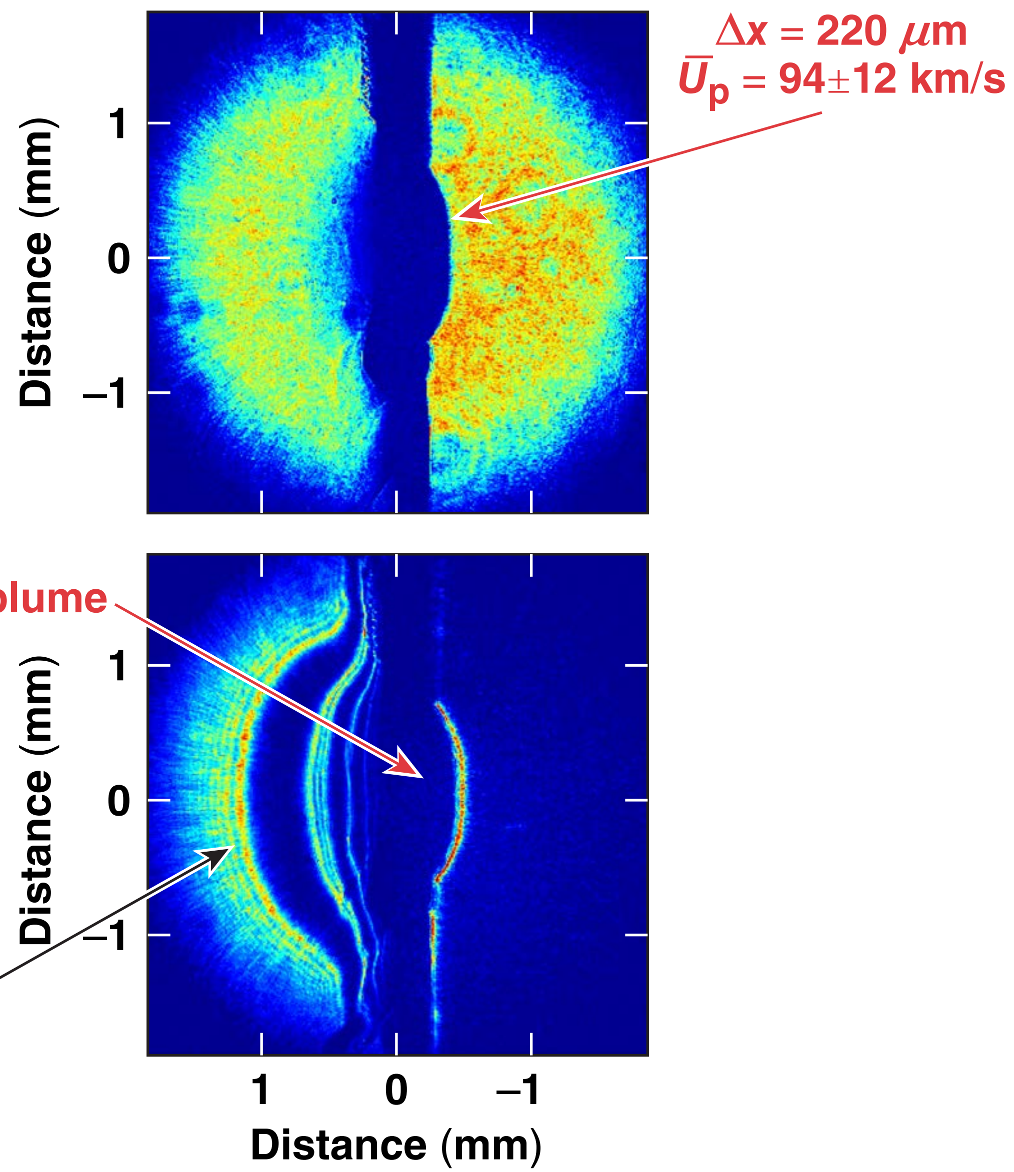
When shocked to 13.2 Mbar, CH releases into a vacuum at ~90 km/s— 3× U_p and in agreement with LEOS 5111

VISAR provides the breakout time and initial conditions

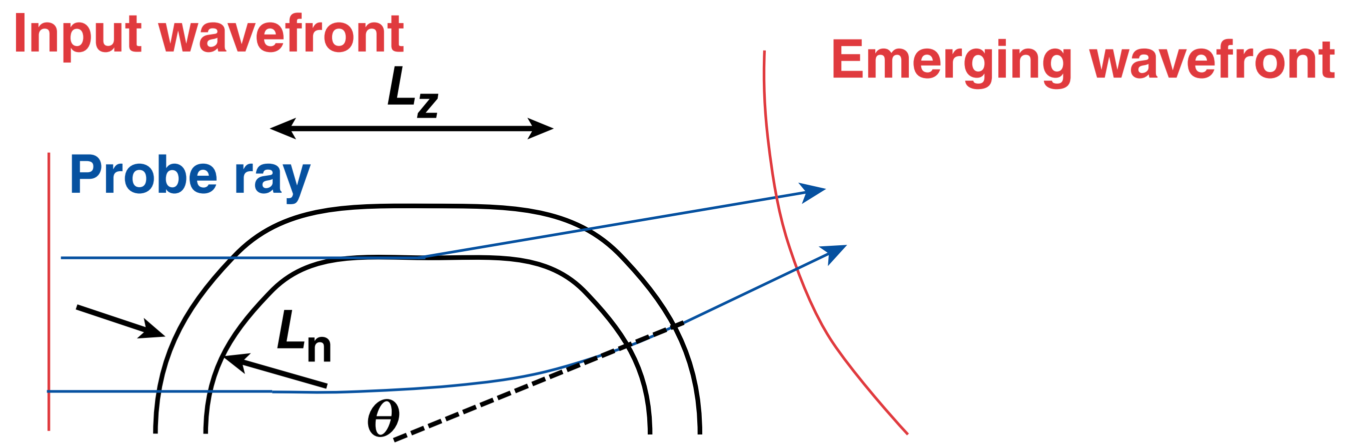


U_s = 42 km/s
U_p = 30 km/s
13.2 Mbar
>5 eV



Refractometry image (schlieren-type imaging with angular filters)

A stratified plasma can be used to model the refraction signal from a release plume



Phase shift through plasma $\Phi = \frac{\omega}{c}\int_0^{L_z} N dl = \frac{\omega}{c}\int_0^{L_z}\sqrt{1-\frac{n_e}{n_c}}\,dl \approx \frac{\omega}{2cn_c}\int_0^{L_z} n_e\, dl$

$$\Phi = \frac{\pi}{\lambda n_c}\int_0^{L_z} n_e\, dl, \quad n_c = \frac{1.1\times 10^{21}\ \text{cm}^{-3}}{\lambda^2_{\mu m}}$$

Assumptions:

$n_e < n_{c,\text{probe}}$

$\theta \ll 1(\text{radian})$

Ray divergence through plasma $\theta = \frac{2\pi}{\lambda}\frac{\partial\Phi}{\partial r} \cong \frac{n_e L_z}{n_c L_n}$

The refraction angle is proportional to the plasma density and L_z/L_n.

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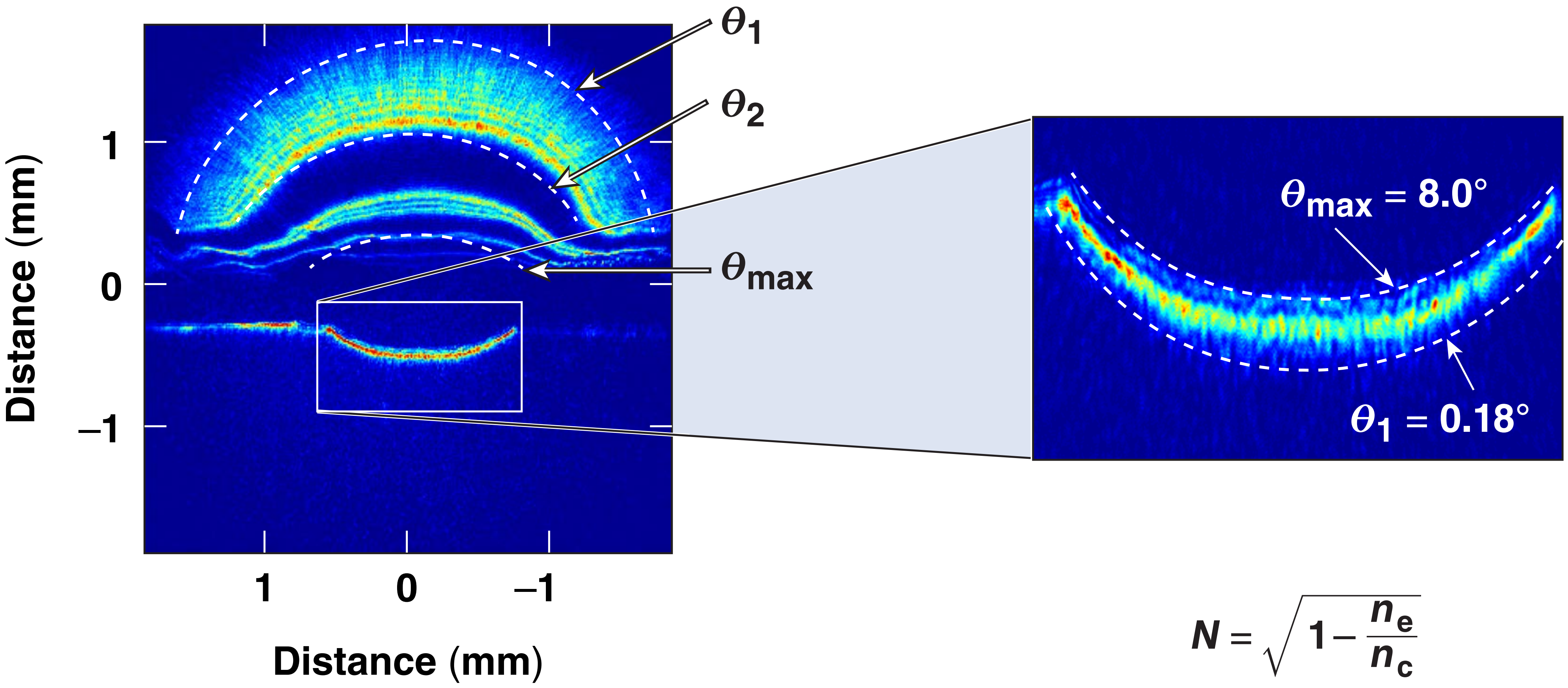
The electron density and density-gradient scale length of the release wave are measured assuming a plasma model for the refractive index



$$N = \sqrt{1 - \frac{n_e}{n_c}}$$

- Electron density: 5×10^{19} cm^{-3}
- Density-gradient scale length: 35 μm

$$n_c = 1.6 \times 10^{22}\ \text{cm}^{-3}$$

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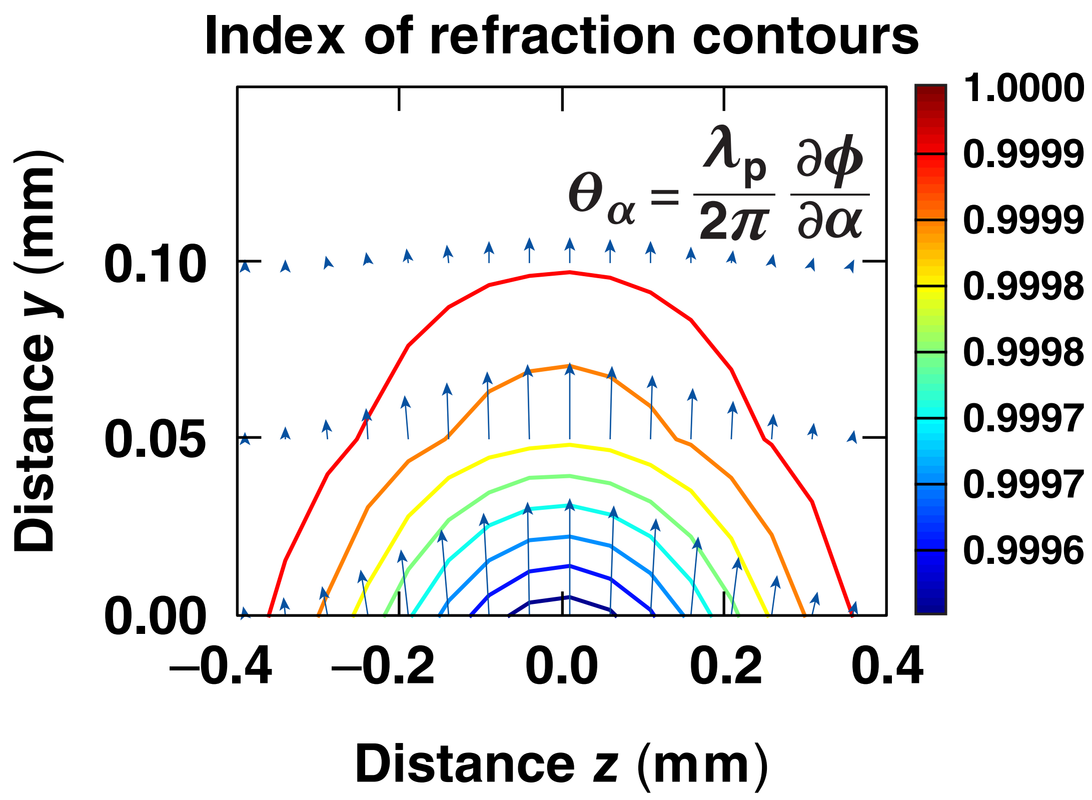
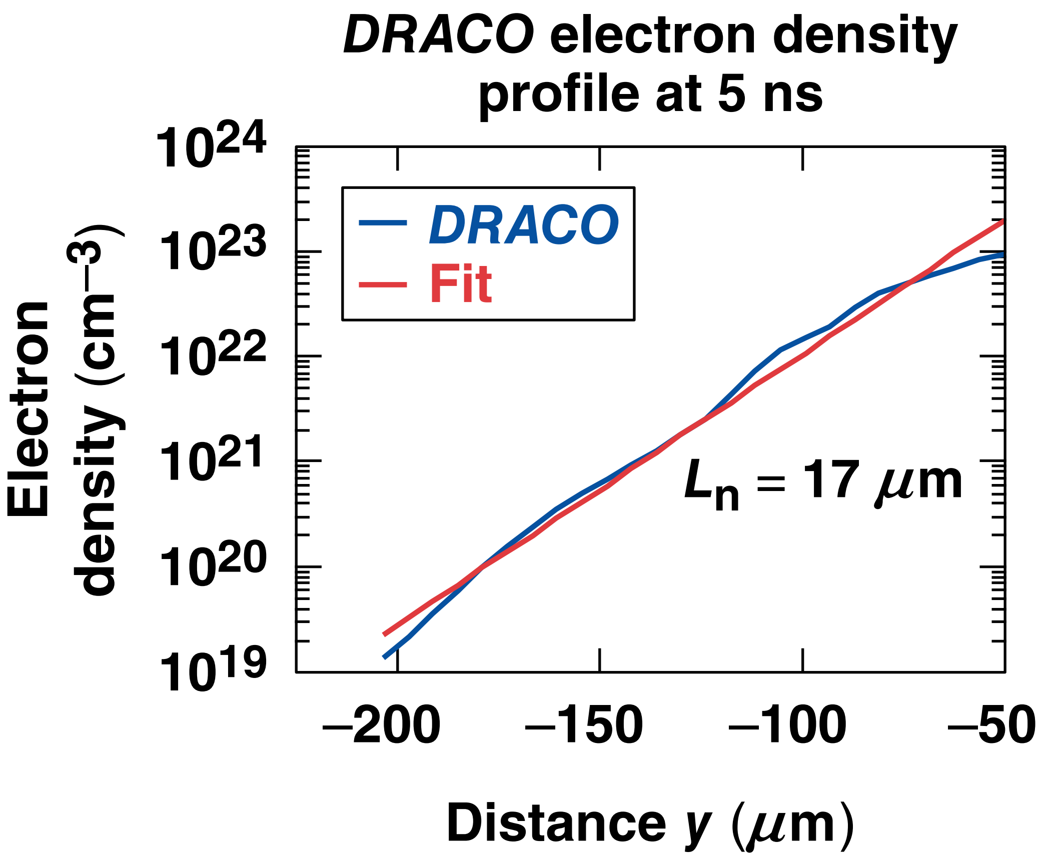
The axial density profile is assumed to be exponential and the transverse shape is fit to the probe images

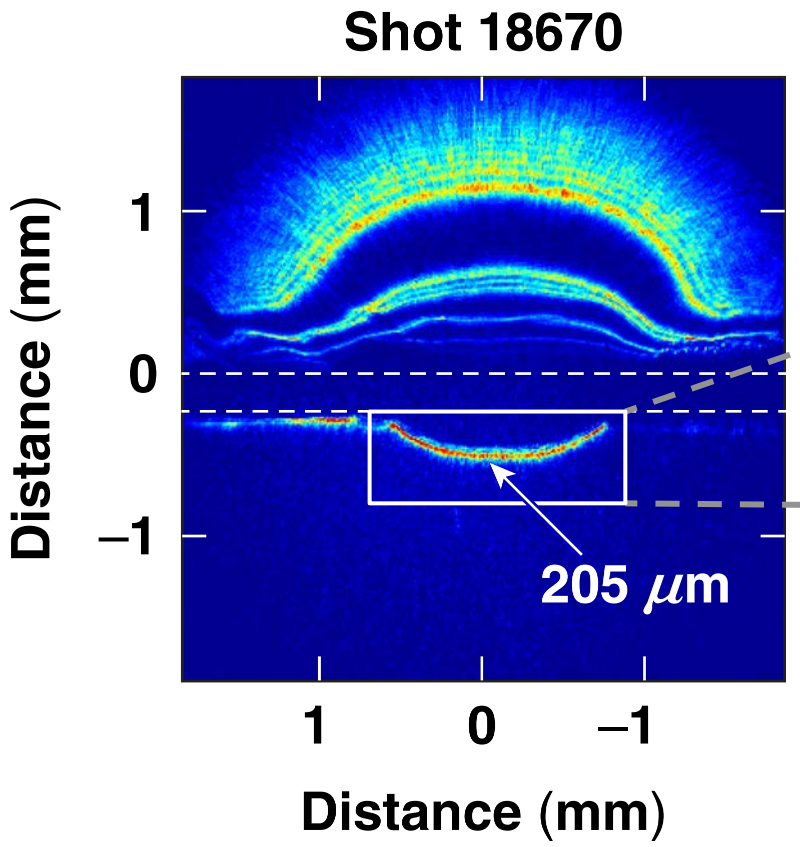




$$n_e = n_0 e^{\frac{-(x^2+z^2)^g}{2\sigma^2}} e^{\frac{-y}{L_n}}$$

$$N = \sqrt{1 - \frac{n_e}{n_c}}$$

The full diagnostic system was simulated in *FRED** and an analytic release density profile was used in the optical model to create a synthetic AFR image



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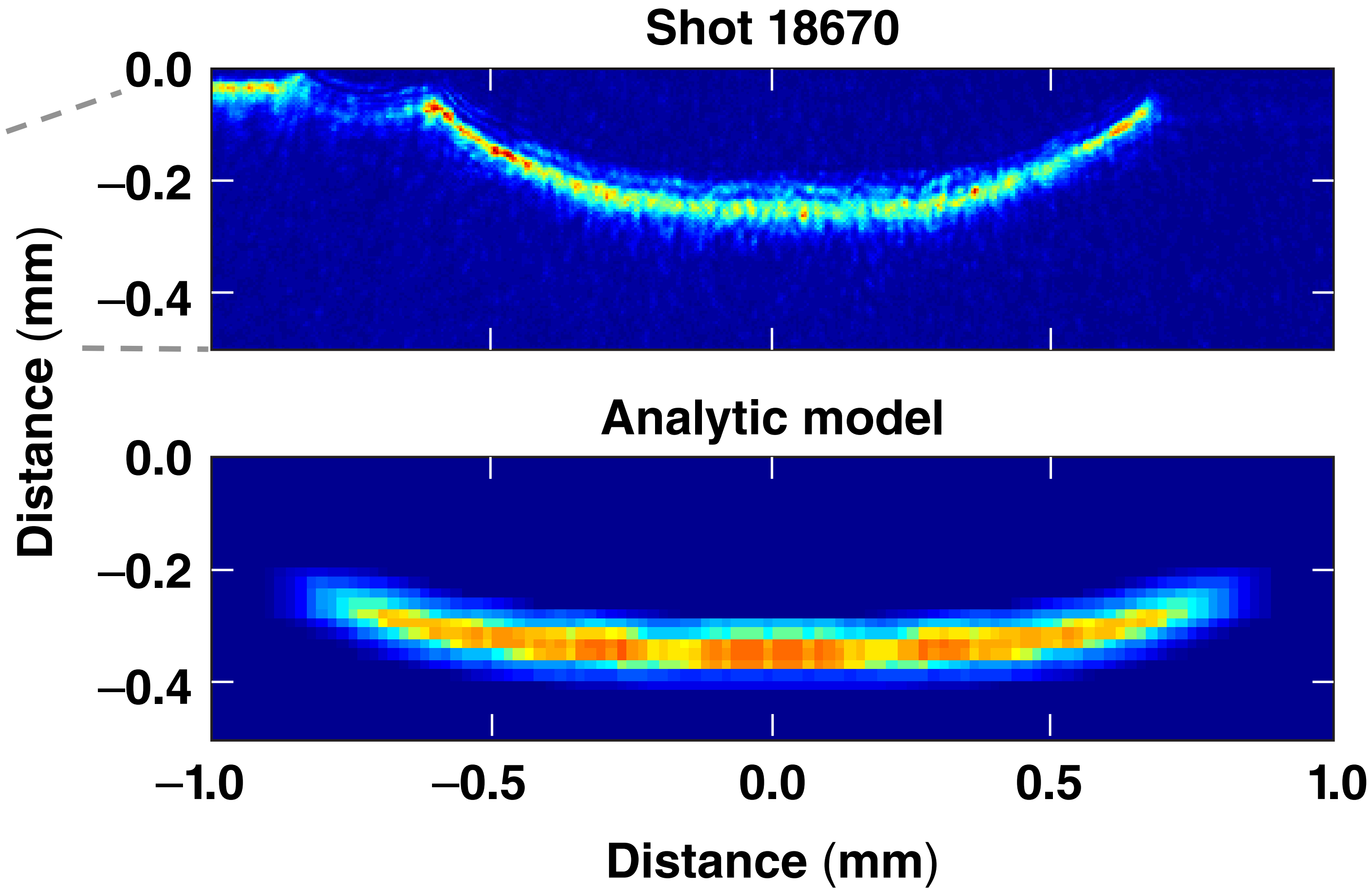

	Analytic
n_0 (cm^{-3})	3.0×10^{22}
Scale length (μm)	15

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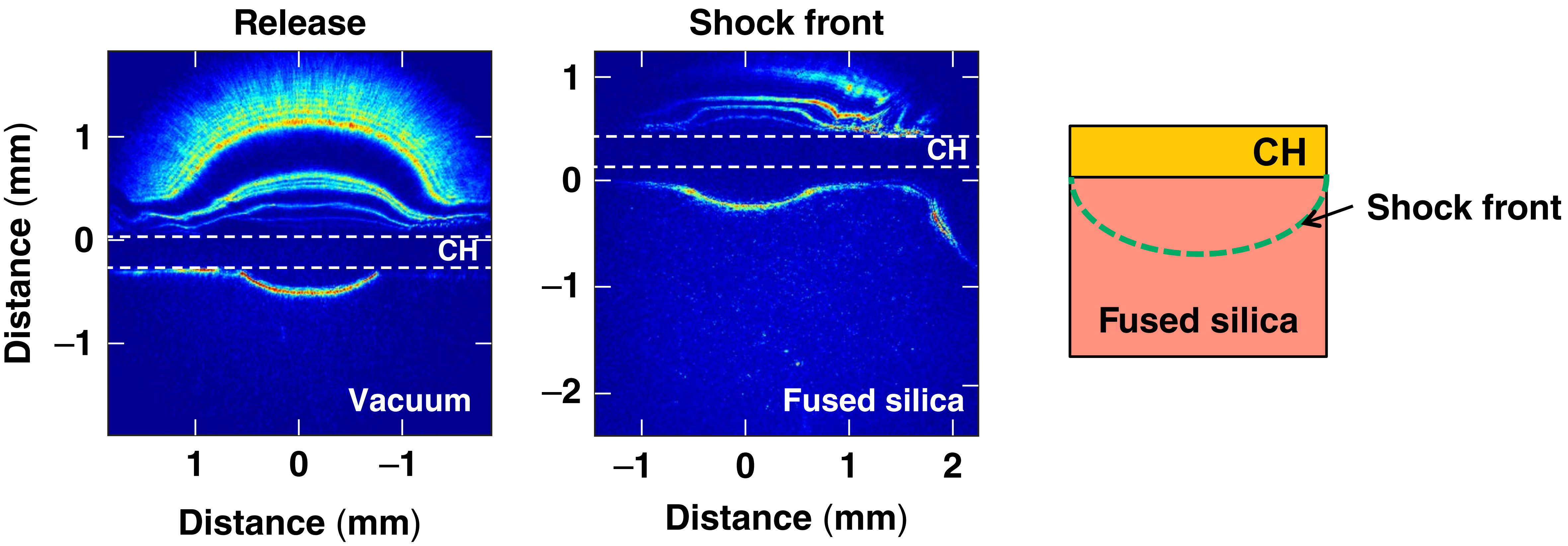
*Photon Engineering, LLC, Tucson, AZ 85711.

Refraction data from a release plume are similar in size and extent to those in a shock front



Scale length = 15 μm

Scale length = 8 μm

The scale lengths of the release plume and shock front produce refraction outside the acceptance angle of the optics.

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