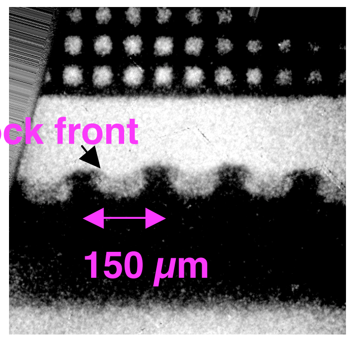
An experimental study of the effect of shock proximity on the Richtmyer-Meshkov instability at high Mach number



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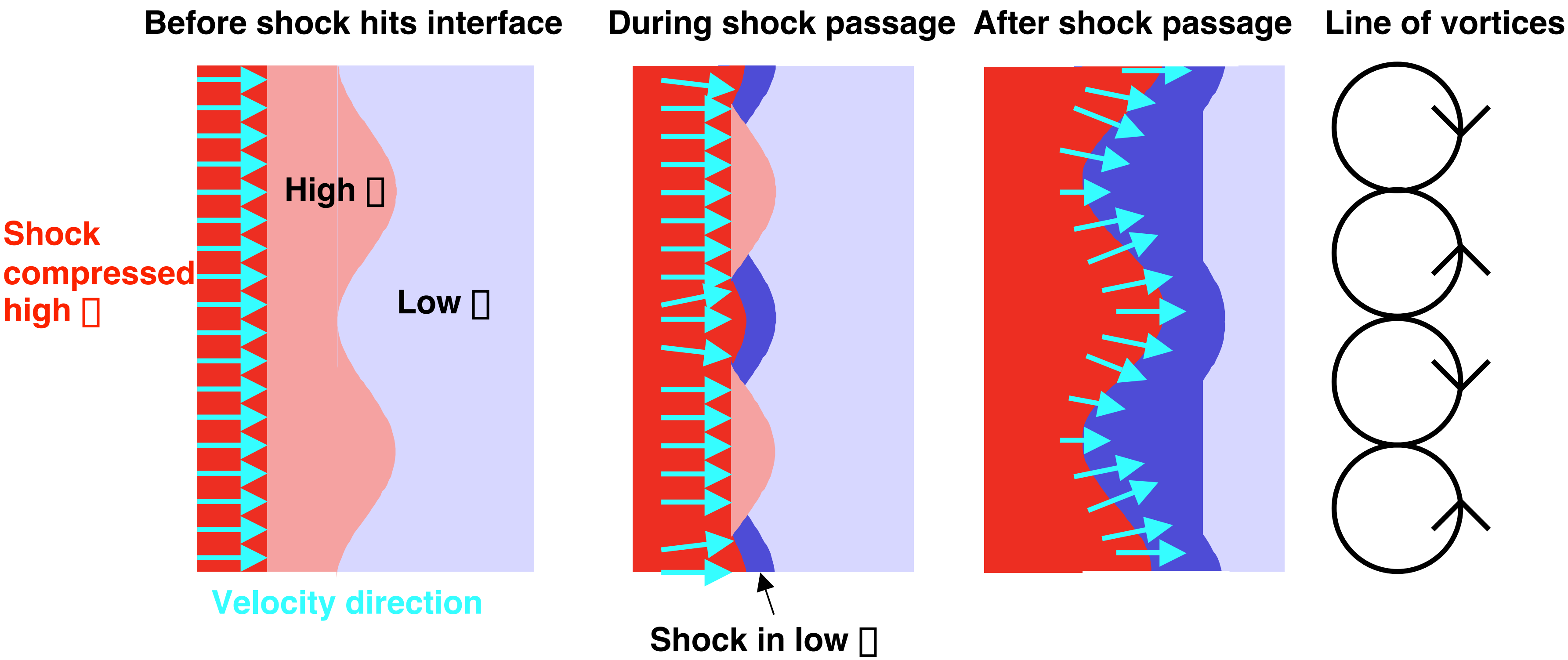
Summary

- We have used the Omega laser to generate a nearly steady interface velocity for Richtmyer-Meshkov experiments
  - The interface is a heavy-to-light (12:1) density step
  - The incident shock Mach number is ~10
  - The shock velocity is only about 20% higher than the interface velocity
- An initially sinusoidal perturbation with $\square$=150 μm, $\square_0$=7 μm (k$\square_0$=0.3) grows according to incompressible models
- The growth of with $\square$=150 μm, $\square_0$=22 μm (k$\square_0$=0.9) is about half that predicted from incompressible models
  - The shock remains very close to the spike tips as the perturbation grows
  - An analytical model which accounts for the effect of the shock proximity predicts the reduced growth

The Richtmyer-Meshkov instability occurs at an interface impulsively accelerated by a shock

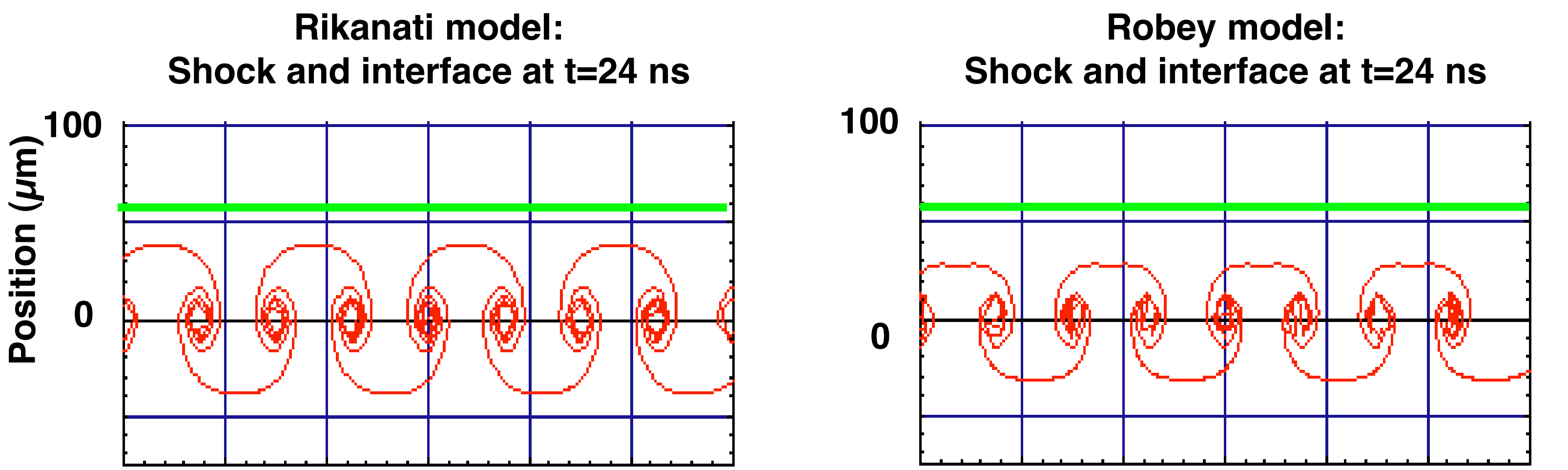


- The interface may be at a density decrease or increase in the propagation direction
  - These experiments are at a density decrease
- A perturbation at the interface creates a velocity perturbation (vorticity field)
- The perturbation grows linearly as $\eta(t) = kA^*\left(\frac{\eta^* + \eta_0}{2}\right)u_c t$ (Meyer and Blewett, 1972)

Laser experiments are important to understand effects of compressibility (high Mach number)

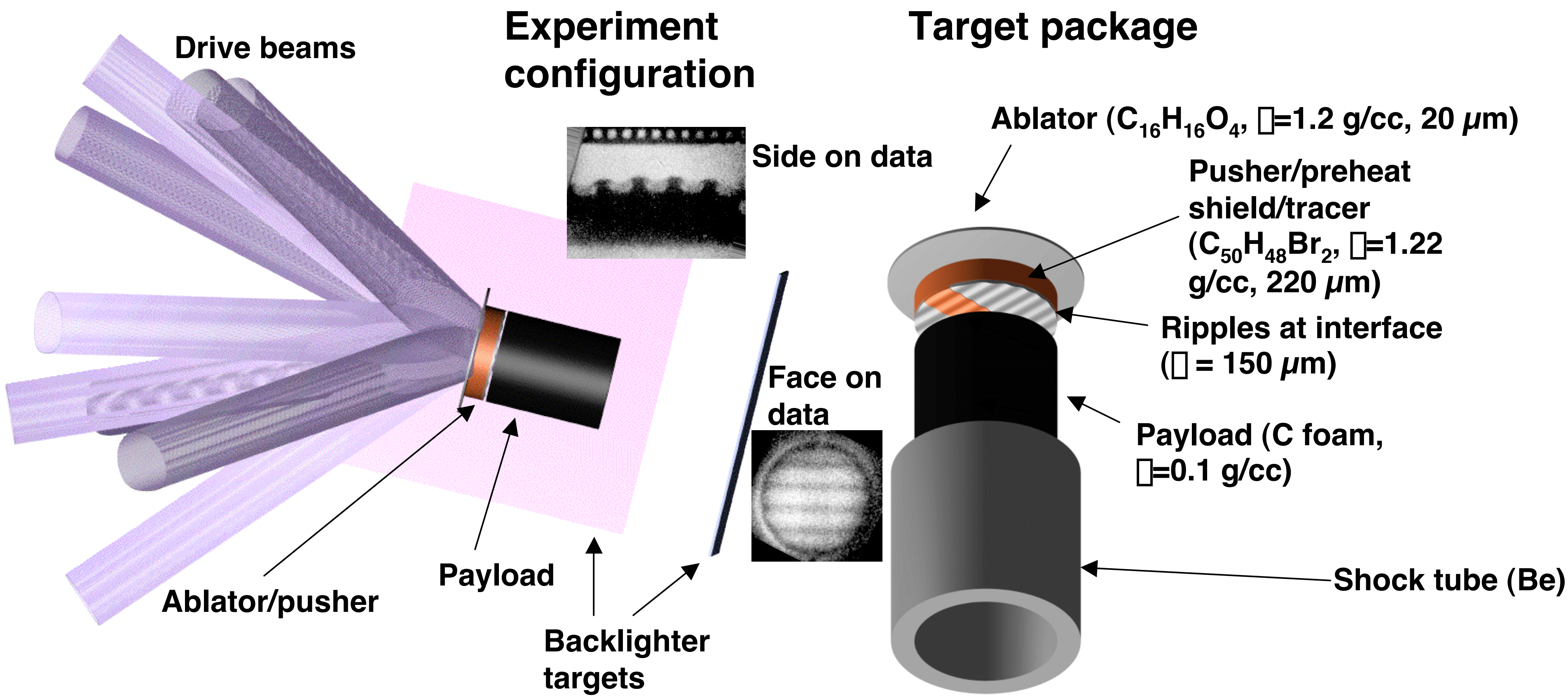
- Compressibility results in a shock front which remains close to the interface
  - $u_c \sim s_f$, where u_c is the interface speed and s_f is the receding shock speed
- Incompressible models (Meyer-Blewett, 1972; Sadot, 1998) predict that spike tip moves faster than shock
- Various models predict reduction in growth rate due to shock proximity:
  - Holmes et al., (1999) $\dot{\eta} = \dot{\eta}_{IM} / \left[1 + \dot{\eta}_{IM} / (s_f - u_c)\right]$, where $\dot{\eta}_{IM}$ is $k u_c A^* (\eta^* + \eta_0)/2$.
  - Hurricane et al., (2000) $\dot{\eta} = u_c (1 - u_c / s_f) \tanh\left[\dot{\eta}_{IM} / u_c (1 - u_c / s_f)\right]$
- Laser experiments at Mach ~15 (Dimonte, 1996; Holmes, 1999; Farley 1999) may show large amplitude effects rather than compressibility effects (Ben-Dor et al., 2001)
  - $k\eta_0$ = 2 (Dimonte/Holmes), $k\eta_0$~2.7 (Farley)
  - Rikanati et al. (2000) predicts $\dot{\eta}/\dot{\eta}_{IM}$ at Mach 15 of ~0.9 for $k\eta_0$ = 0.9, 0.65 for $k\eta_0$ = 2
- On Omega we have investigated this with $k\eta_0$ = 0.9, u_c = 21.9 μm/ns, s_f = 26.1 μm/ns

A model of vortex evolution (Rikanati, 1998) was proposed for low Atwood number RMI



- This model calculates growth rates from analytical solutions to vortex flow problem
- An extension of this model (Robey, 2001) constrains the shock front to be flat by introducing mirror image vortices
  - However, the shock front is not in reality flat
- Robey's is the only model which predicts an increase in growth rate after initially slow growth

This experiment uses an 11 ns laser drive to create a steady shock incident on a modulated interface



- Radiography is done on two axes, along target axis and perpendicular to modulations
- Target package is encased in a beryllium shock tube

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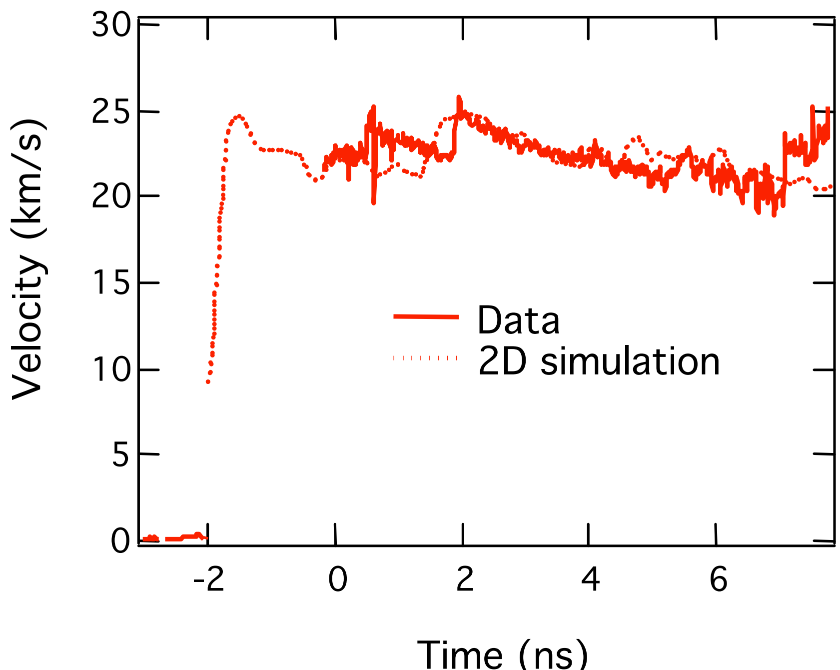
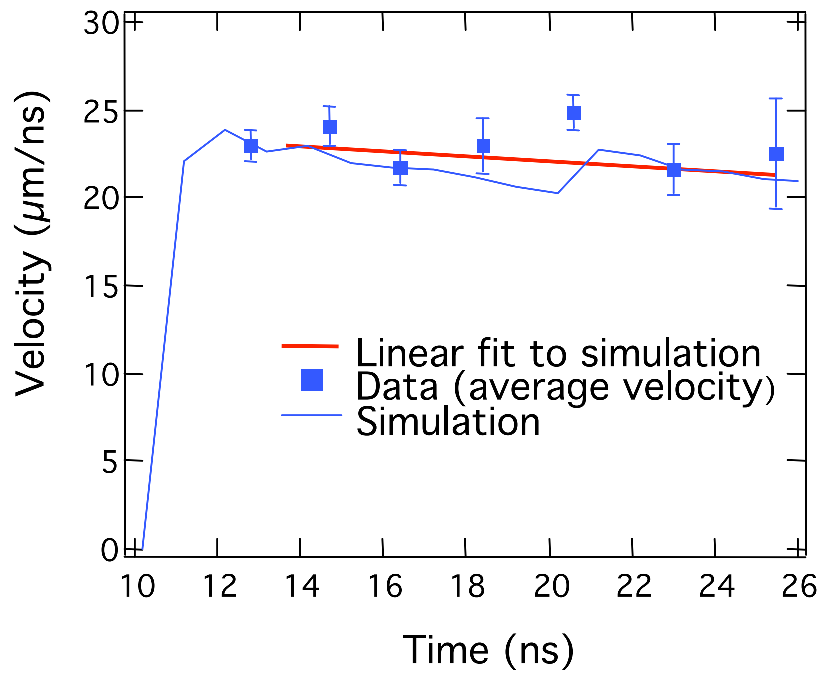
The incident shock and interface velocities are constant within ±5% RMS

Incident shock velocity (VISAR measurement)



Interface velocity (position measurement)



- Incident shock velocity is measured with payload removed using VISAR
  - Result 22.0±0.2 μm/ns, ±5% (RMS) variations
- The shock is incident on a 12:1 density contrast
- The interface position is measured by side-on radiography
  - Average interface velocity 21.9±1.0 μm/ns
  - Transmitted shock velocity 26.1±0.5 μm/ns

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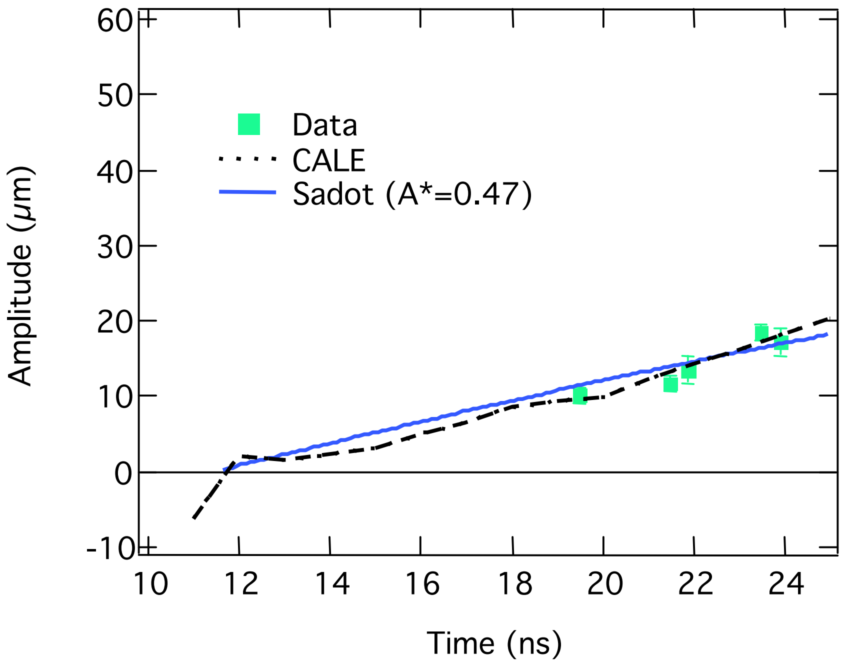
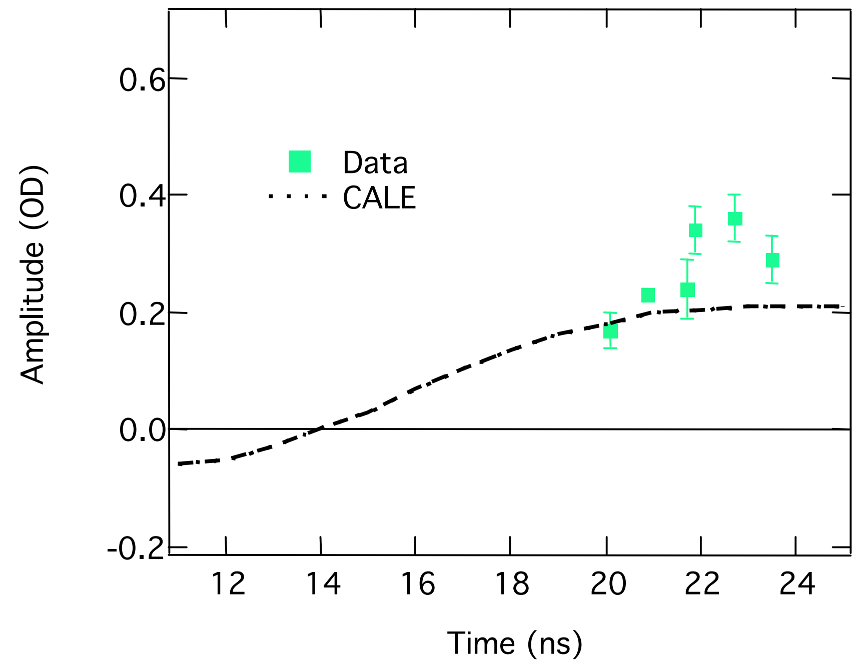
At low initial amplitude results show no effect of shock proximity and little nonlinearity

Side-on radiographs, $\square_0$=7 μm



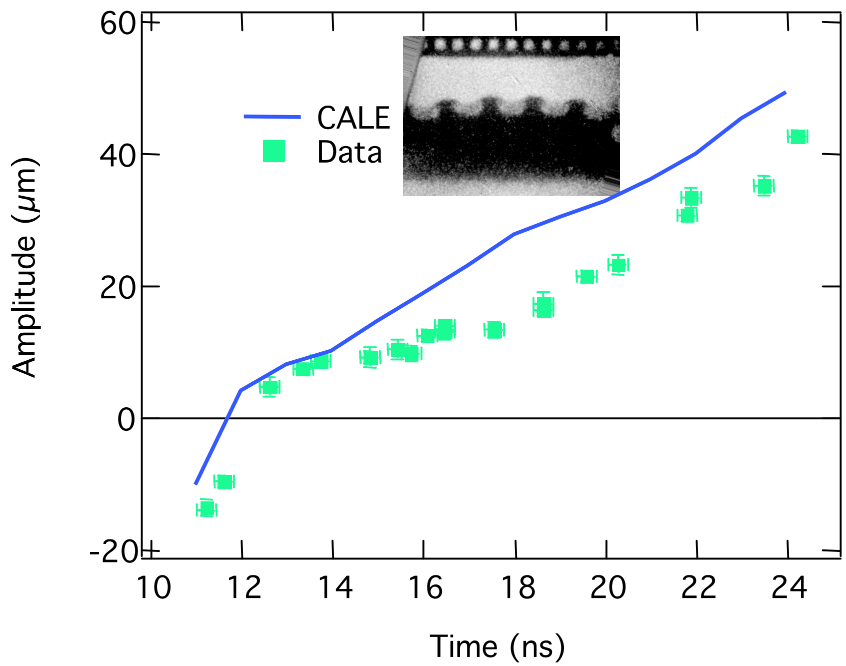
Face-on radiographs, $\square_0$=7 μm



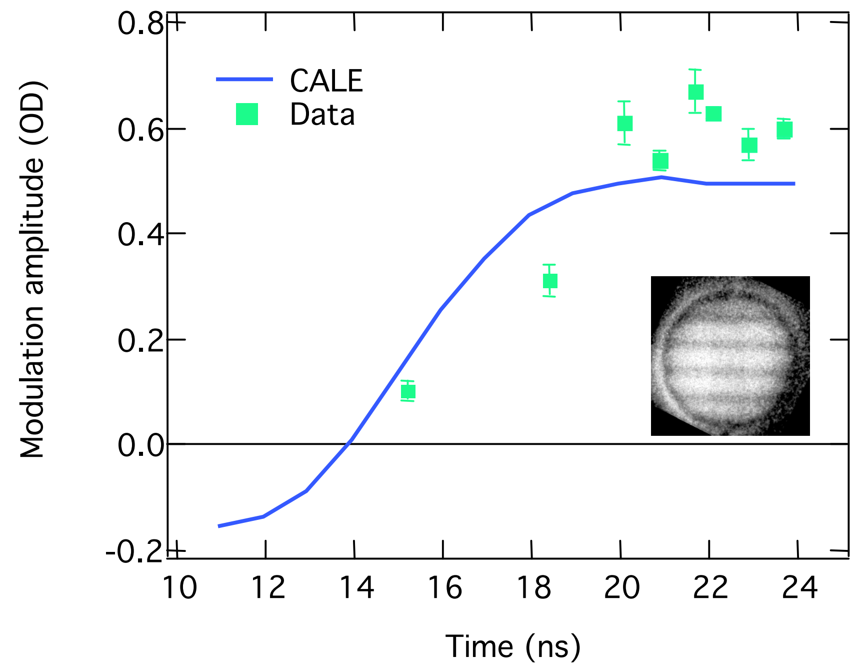
- The nonlinear, incompressible model of Sadot (1998) was used to describe the side-on data with an inferred post-shock Atwood number of 0.47
    - Atwood number of 0.47 agrees with one-dimensional simulations
- Linear growth rate $\square$ is 1.5 μm/ns
- CALE simulations agree with the data

Larger initial amplitude results show reduced growth due to shock proximity

Side-on radiography results, □$_0$=22 μm



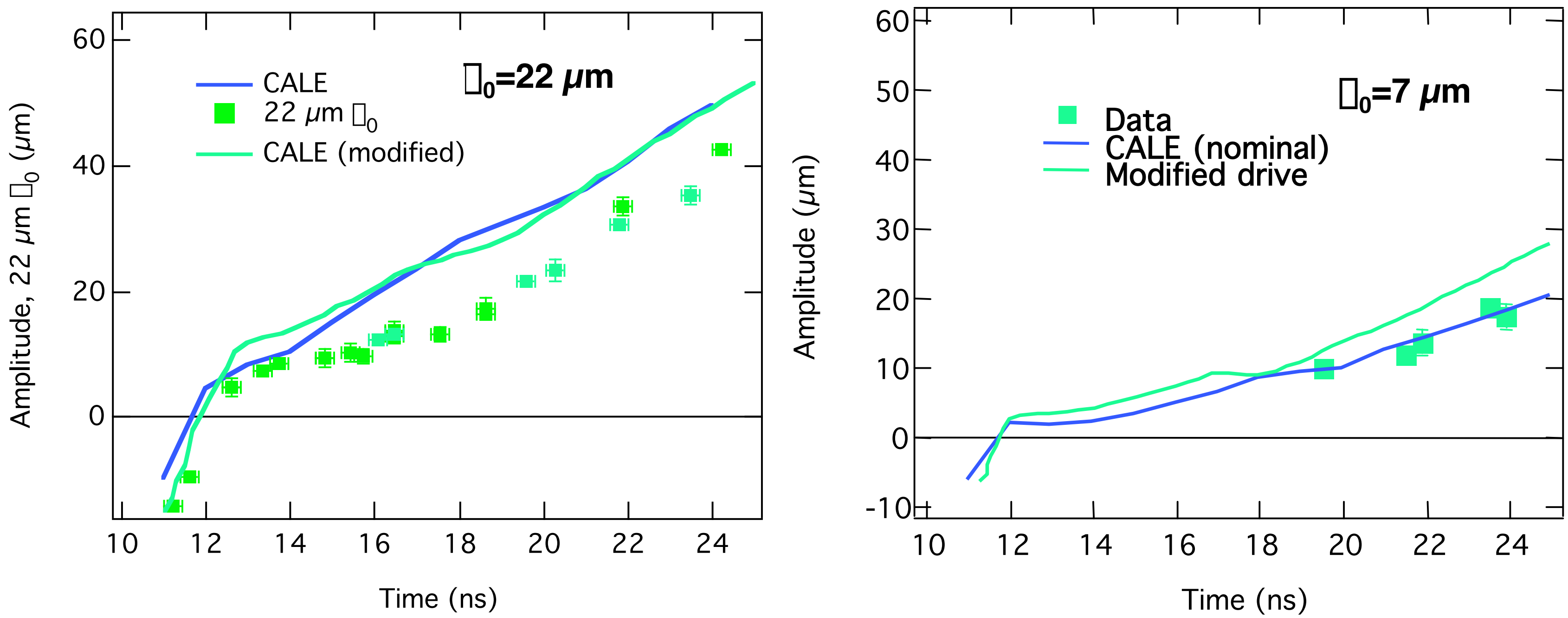
Face-on radiography results, □$_0$=22 μm



- Linear growth rate would be 4.8 μm/ns
- The average □ is 2.4±0.1 μm/ns
  - Before 18 ns □ is about 1.9±0.1 μm/ns
- The CALE simulation gives a growth rate of 3.9 μm/ns before 18 ns, 3.7 μm/ns average 12-24 ns

We may constrain the CALE simulations to come closer to the modulation growth at λ=150, η_0=22 by changing the drive

Growth at λ=150 *μm* vs. time



- The modified drive gives a growth rate at early time of 3.0 *μ*m/ns
- The modified drive does not predict the λ=150 *μ*m, η_0=7 *μ*m data
- We are currently investigating EOS issues
- The discrepancy between CALE and the data is currently not understood

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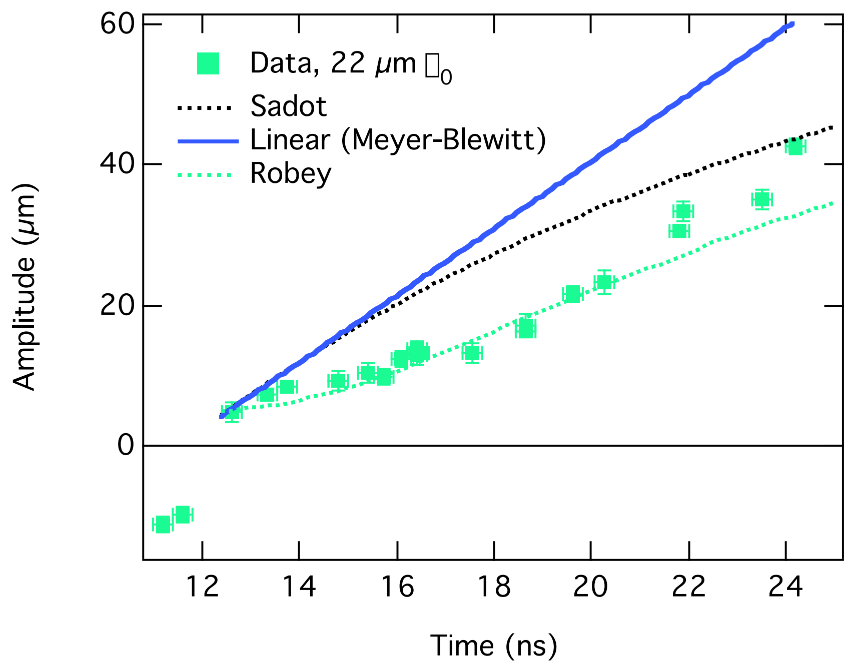
The vortex model of Robey does predict growth very much like that seen

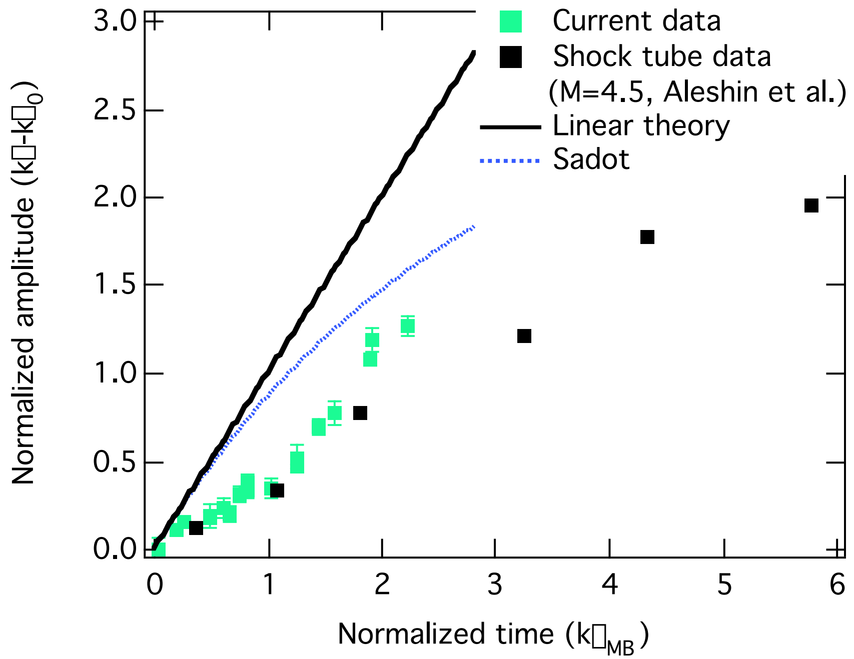
Side-on radiography results



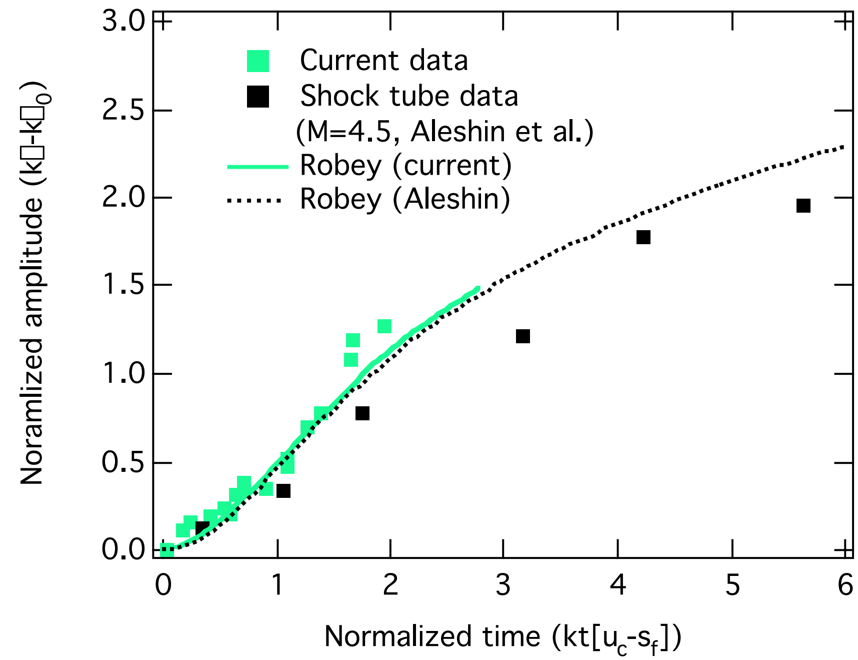
- The model predictions are offset to the first observed data point

The data may be compared with the shock tube data of Aleshin et al.

Time normalized to Meyer-Blewett growth

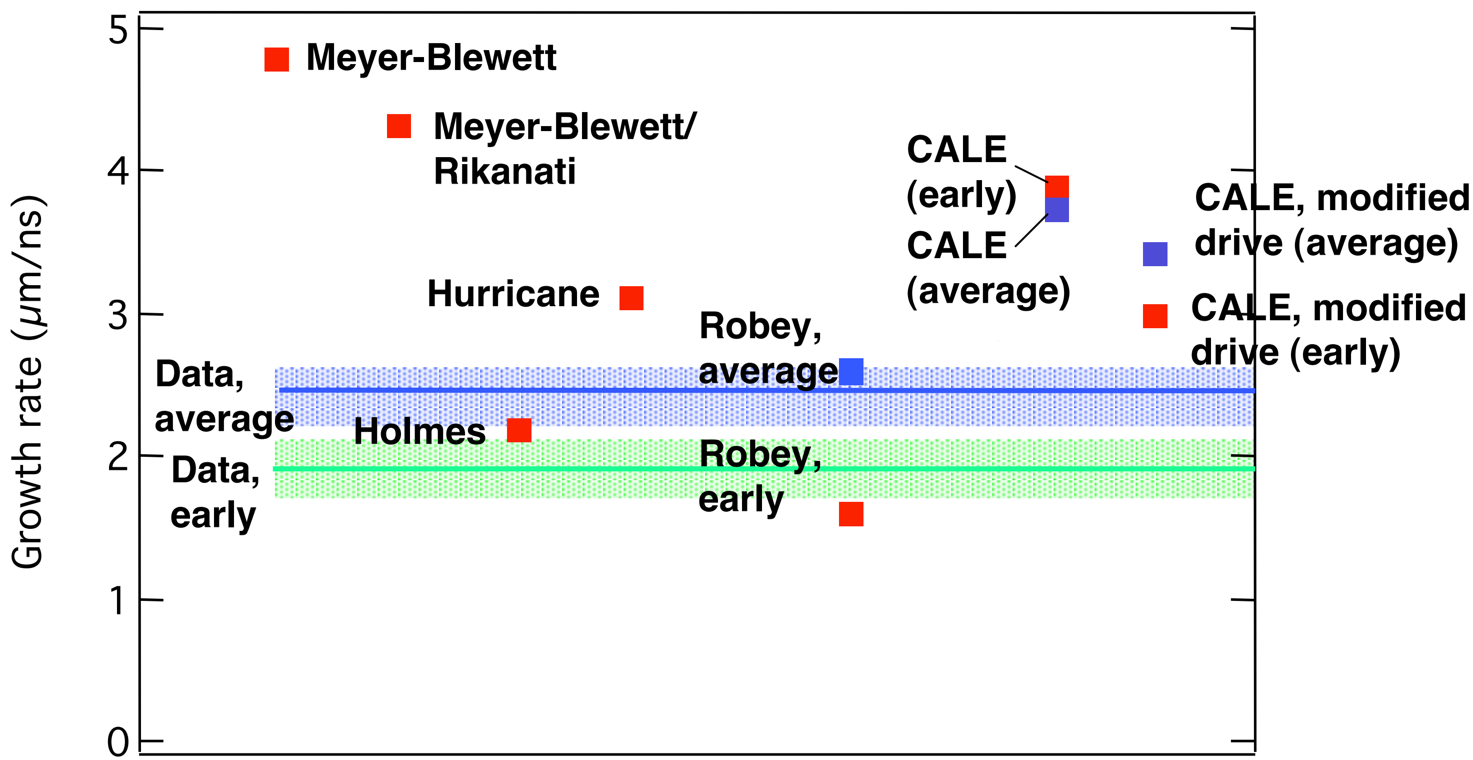


Time normalized to shock recession



- One normalization is k□ vs. $k□_{IM}$ (Meyer-Blewett, shows nonlinearity)
- Another normalization is k□ vs $k^*(u_c-s_f)^*t$ (shows shock proximity)

The initial growth rate is much lower than linear or large-initial-amplitude models predict



- Only the Robey model predicts an increase in velocity later in time (as the shock recedes)

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