Ablative Richtmyer–Meshkov Instability: Theory and Experimental Results

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Summary
The ablative Richtmyer–Meshkov (RM) evolution is sensitive to coronal conditions

- In the presence of mass ablation, the RM evolution depends on the size of conduction zone $D_c$
  - $kD_c \ll 1$, ablation front is unstable (Landau-Darrieus instability)
  - $kD_c > 1$, ablation front is stable, perturbations oscillate* with $\omega = k \sqrt{V_a V_{bl}}$
- $V_{bl}$ and $D_c$ depend on the thermal transport models
- Shock velocity and RM measurements are consistent with new nonlocal and time-dependent flux-limiter models

RM evolution is a good test of hydrocodes

During rippled shock propagation, an ablative Richtmyer–Meshkov-like instability can occur.
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The sharp-boundary model* assumes that perturbation is localized inside the conduction zone.

\[ \rho/\rho_{\text{max}} \]

Conduction zone \( D_c \)

Deposited laser energy \( E_L/E_{L\text{max}} \)

\( \mu \) for Laser is not visible.

Ablation-front perturbations asymptotically oscillate in time

\[ \eta_a = \eta^{cl}(t) - \eta^{cl}_\infty(t) + e^{-2kV_a t}(\alpha \cos \omega t + \beta \sin \omega t) + \eta_v(t) \]

Vorticity set by shock

\[ V_a = 5 \, \mu m/\text{ns} \]
\[ C_s = 55 \, \mu m/\text{ns} \]
\[ V_{bl} = 80 \, \mu m/\text{ns} \]
\[ \lambda = 30 \, \mu m \]

\[ \omega = k \sqrt{V_a V_{bl}}, \quad V_{bl} \propto V(1/k) \]
A detailed comparison between the model and 2-D simulations shows a discrepancy at the beginning of the pulse.

- $D_2$ foil, $I = 4 \times 10^{14}$ W/cm$^2$, $\lambda = 30$ $\mu$m
The discrepancy between model and simulation is due to a small conduction zone at the beginning of the pulse.

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The location of the phase reverse depends on the size of the conduction zone.
The size of the conduction zone depends on the thermal transport model

- Flux-limited thermal transport* has traditionally been used in hydrocodes
  
  \[ q_{\text{SH}} = -\kappa \nabla T \quad q_{\text{FS}} = nTV_T \]

- Sharp cutoff \( q_{\text{eff}} = \min(q_{\text{SH}}, \, fq_{\text{FS}}) \)

- \( 0.04 < f < 0.1 \)

Perturbation evolution is very sensitive to the transport model parameters

- $D_2$ foil, $I = 2 \times 10^{14} \text{ W/cm}^2$, $\lambda = 20 \mu \text{m}$
A single-valued flux limiter is not consistent with the experimental results.

**RM Experiment**
- 2-ns square pulse, $I = 4 \times 10^{14} \text{ W/cm}^2$
- CH foil $d = 40 \ \mu\text{m}$, $\lambda = 20 \ \mu\text{m}$

**Shock-breakout measurements**

A flux limiter $f = 0.06$ is consistent with dual shock velocity measurements*

A nonlocal transport model has been developed to test the results of flux-limited approximation.

Electric field  
Collisional frequency  

\[ v \frac{\partial f}{\partial x} + \frac{eE}{m} \frac{\partial f_0}{\partial v_x} = - \dot{\nu} (f - f_0) \Rightarrow f = \int^x \left( f_0 - \frac{eE}{mv} \frac{\partial f_0}{\partial v_x} \right) e^{-\xi} \frac{dx'}{\lambda \cos \theta}, \quad \xi = \int^x \frac{dx''}{\lambda \cos \theta} \]

\[ j_x = e \int d^3 v v_x f, \]

\[ q_{NL} = \frac{m}{2} \int d^3 v v^2 v_x f \]

\[ j_x = 0 \Rightarrow E \]

Consistent with FP simulation*

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The nonlocal transport model is consistent with shock timing measurements
Results of 2-D calculations with the time-dependent flux limiter are consistent with the RM growth measurements for different wavelengths.

- 2-ns square pulse with peak intensity $I = 420$ TW/cm$^2$, $d_{\text{CH}} = 60\mu$m
- Simulations use SESAME EOS and full 2-D ray tracing
Summary/Conclusions

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