The stages of an inertial confinement fusion (ICF) implosion

Maintaining target integrity throughout the implosion is critical to achieving thermonuclear ignition.

1. Shock propagation
   - Fusion burn/ignition
     - Hot-spot ignition
     - $\rho R_{HS} > 0.3 \text{ g/cm}^2$
     - $T_{HS} > 10 \text{ keV}$
   - Absorption
     - $I \sim 10^{13} \text{ to } 10^{14} \text{ W/cm}^2$

2. Acceleration phase
   - Rayleigh–Taylor growth and feedthrough
     - $I \sim 10^{15} \text{ W/cm}^2$

3. Deceleration phase
   - Hot-spot formation
   - Rayleigh–Taylor growth

4. Peak compression
   - Hot dense matter
   - Warm dense matter
   - Preheat

Hot-spot ignition
Introduction to the Rayleigh–Taylor instability

• Rayleigh–Taylor instability (RTI)
  – instability at the interface of fluids with different densities when a lighter fluid supports a heavier fluid
  – in ICF, RTI occurs during the acceleration and deceleration phases of the implosion
  – modulations grow exponentially early in time, then grow linearly after reaching the saturation level \((Z_k = \lambda/10)\) with the growth rate given by\(^*\)

\[
\gamma_{RT} = \alpha \sqrt{\frac{k \times g}{1 + k \times L_m}} - \beta \times k \times V_a^+\]

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>(\alpha)</td>
<td>Constant</td>
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<tr>
<td>(\beta)</td>
<td>Constant</td>
</tr>
<tr>
<td>(k)</td>
<td>Modulation wave number</td>
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<tr>
<td>(g)</td>
<td>Interface acceleration</td>
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<tr>
<td>(V_a)</td>
<td>Ablation velocity</td>
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<tr>
<td>(L_m)</td>
<td>Density scale length</td>
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Previous RT experiments demonstrated decreased instability growth at peak laser intensities of $1 \times 10^{15}$ W/cm$^2$ in CH targets caused by electron preheat*.

Target preheat leads to increased density scale length ($L_m$) and ablation velocity ($V_a$), resulting in decreased RT modulation growth.

\[ \gamma_{RT} = \alpha \cdot \sqrt{\frac{k \cdot g}{1 + k \cdot L_m}} - \beta \cdot k \cdot V_a \] **

Planar CH, SiO$_2$, and CH–SiO$_2$ targets are driven by 10 to 12 drive beams, while an x-ray backlighter is used to measure areal density modulation growth.
Targets were seeded with an intensity-imprinted 2-D modulation, while pre-imposed mass modulations were also used on CH and CH–SiO₂ targets.

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40-μm-thick CH targets driven at low intensities (5 × 10^{14} W/cm^2) show significant growth up to the modulation saturation amplitude.
20-μm-thick intensity-imprinted SiO$_2$ targets with 1.5- and 3-μm CH ablators show modulation growth at low intensities.
17-μm-thick SiO₂ targets with a perturbed 3-μm CH ablator show significant modulation growth in SiO₂ at low intensities.

- Pre-imposed modulations
At high intensities ($1 \times 10^{15} \text{ W/cm}^2$) imprinted modulations grow in SiO$_2$, while CH targets of comparable mass show no growth.
17-μm-thick SiO₂ targets with a perturbed 3-μm CH ablator show no significant instability growth at high intensities, while SiO₂ without CH shows significant modulation growth.

- Pre-imposed (CH–SiO₂) and imprinted (SiO₂) modulations

![Graphs showing intensity and modulation amplitude over time for different wavelengths and materials.](image)
Intensity-imprinted targets with CH ablators show no significant modulation growth at high intensities.
Rayleigh–Taylor (RT) experiments at $1 \times 10^{15}$ W/cm$^2$ with CH and SiO$_2$ ablators show significant growth differences

- At peak drive intensities of $5 \times 10^{14}$ W/cm$^2$, both CH and CH–SiO$_2$ targets show significant 2-D modulation growth
- At peak drive intensities of $1 \times 10^{15}$ W/cm$^2$
  - CH targets with 2-D modulations (pre-imposed and intensity imprinted) show a reduction in RT growth caused by electron preheat
  - SiO$_2$ targets with 2-D intensity-imprinted modulations show significant RT growth
  - CH–SiO$_2$ targets with 2-D modulations (pre-imposed and intensity imprinted) show a reduction in RT growth