Room-temperature, ignition-scale hohlraum experiments on NIF


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NIF room-temperature ("warm") ignition-scale hohlraum experiments with higher-Z gas fill

Motivation:
• Hotter hohlraum plasma could reduce inner-beam SRS (more Landau damping)
• Higher Z hohlraum gas fill absorbs more laser via inverse bremsstrahlung
• Warm shots allow gases that freeze at cryo, e.g. hydrocarbons
• Warm shots easier to field, cheaper (no cryo hardware)

Shape: in-flight shell vs. stagnated hotspot
• Warm hotspots close to round with less $\Delta \lambda$ than cryos
• But warm shell pancaked – need more $\Delta \lambda$ to make round
• Opposite "swing" of cryos – shell round but hotspot pancaked

Backscatter: Warms have less inner-beam SRS, more outer-beam SBS
• Pure $\Delta \lambda$ scaling or intrinsic effect of gas fill?

Does higher Z gas fill improve inner-beam propagation = round implosion with less cross-beam transfer to inners ($\Delta \lambda$)? Jury still out.
Warm shots use hydrocarbon gas fills, retuned laser picket and trough

<table>
<thead>
<tr>
<th></th>
<th>Cryo</th>
<th>Warm</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hohlraum fill</td>
<td>0.96 mg/cc He(^4)</td>
<td>0.82 mg/cc C(<em>5)H(</em>{12})</td>
<td>higher Z, same (n_e)</td>
</tr>
<tr>
<td>Capsule fill</td>
<td>D-He(^3)</td>
<td>propane: C(_3){H or D}(_8)</td>
<td>D, He leak warm</td>
</tr>
</tbody>
</table>

- Higher warm picket: more energy to burn through higher-Z gas
- Lower trough to compensate

Main pulses differ: shots have different design histories

19ns: shown on next slide
Higher Z hohlraum gas fill increases inverse bremsstrahlung laser absorption, gives hotter plasma

\[
\kappa_{IB} \propto \left[1 - \frac{n_e}{n_{cr}}\right]^{-1/2} \frac{n_e^2}{T_e^{3/2}} \ln \Lambda \sum_i f_i Z_i^2 \frac{\sum_i f_i Z_i}{\sum_i f_i Z_i}
\]

\[
\text{warm } \kappa_{IB}(C_5H_{12}) = \frac{4.57}{2} = 2.29
\]

Directly depends on gas fill

Hydra modeling: electron temperature at mid peak power (19 ns):

- Warm C\textsubscript{5}H\textsubscript{12}
- Cryo He

\begin{align*}
\text{Warm C}_5\text{H}_{12} & \sim 4 \text{ keV} \\
\text{Cryo He} & \sim 3.4 \text{ keV} \\
\text{difference} & \sim 600 \text{ eV}
\end{align*}

n\textsubscript{e}, T\textsubscript{e}, flows, etc. all depend weakly on \(\kappa_{IB}\)
Implosion must be symmetric for ignition

NIF chamber

gravity

P2>0: sausage: Inners high shell
Hotspot
self emission
Gated X-ray detector

P2<0: pancake: outers high

Outers (44°, 50°)

Inners (23°, 30°)

Cross-beam Energy transfer

X-ray backlighter “ConA” shot

gravity
Warm shot history

- **5**: -300 um: shell pancaked diamond ($P_4 > 0$)
- **3 and 4 (repeat)**: 1.26 MJ round hotspot
- **Shot 6**: +700 um: shell pancaked small $P_4$

**E_{laser} \sim \text{Calendar time}**

- **FY13**
  - 1: 820 kJ, $\Delta \lambda = 1.5$ Å, large pancake
- **2009**
  - Two 500 kJ symcaps.
    - Better inner propagation than cryo: Less inner SRS, more outer SBS, less pancake

**Hohlraum length**

- **2**: 946 kJ, $\Delta \lambda = 3.5$ Å: round hotspot!
- 3.5 Å used subsequently

2D convergent ablator (ConA): in-flight shell shape
Hotspot shape: less transfer to be round warm vs. cryo

- After shots 2 and 4 we chose $\Delta \lambda = 3.5$ Ang. as giving round hotspot

Suggests higher Z improves inner beam propagation
But warm 2D ConA’s (last two shots) revealed pancaked in-flight shell

Cryo
warm

Hydra playbook [O. Jones]: $\Delta \lambda = 4.7 \text{ Å}$ to make warm shell round
Best shape shots

<table>
<thead>
<tr>
<th></th>
<th>$E_{\text{laser}}$ [kJ]</th>
<th>$P_{\text{peak}}$ [TW]</th>
<th>Hohlraum length</th>
<th>$\Delta \lambda_{23,30}$ [Å]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cryo N130314</td>
<td>1340</td>
<td>360</td>
<td>+700 um: low shell $P_4$</td>
<td>6.0, 4.5</td>
</tr>
<tr>
<td>Warm N130627</td>
<td>same</td>
<td>1.06x</td>
<td>same</td>
<td>3.5, 3.5</td>
</tr>
</tbody>
</table>

![Diagram showing sausage and pancake shapes with cryo and warm time lines]
In-flight shell and hotspot shapes “swing” oppositely for warm vs. cryo: pure $\Delta \lambda$ scaling or gas Z effect?

P$_4^1$ and tent distorting hotspot shape

Tent talks (already happened): Nagel, Haan, Town

Warm hotspot also complicated by propane capsule fill: cooler hotspot, significant shell emission

Plot courtesy R. Town

$^1$R. H. H. Scott et al., PRL 2013
Warms have less inner SRS, more outer SBS than cryos. Pure $\Delta \lambda$ scaling, or gas fill effect?

23° SRS

30° SRS: more than 23°'s for warms

50° SBS: more for warms than cryos

*Almost no 44° SBS (DrD sensors)
Jury out on whether higher Z gas fill improves inner beam propagation

- Warm and cryo shots have different symmetry and backscatter
- Purely due to $\Delta \lambda$ or gas Z effect?
- Need to compare implosions with good symmetry throughout time
- Not achieved yet warm, maybe cryo (stalk vs. tent mount)
- Time-varying $\Delta \lambda$ or cone fraction may be needed
- Should check early time symmetry of warm shots – keyhole, re-emit
• BACKUP SLIDES
Jury out on whether higher Z gas fill improves inner beam propagation

Cryo shape:
- 2D ConA’s: in-flight $P_2$ sausage and $P_4$
- Reduce $\Delta \lambda$ to remove $P_2$, +700 um hohlraum to remove $P_4$
- Round shell swings to pancaked hotspot – tent?

Warm shape:
- Opposite $P_2$ swing from cryo: shell pancake but hotspot round!
- More $\Delta \lambda$ needed to remove shell $P_2$
- Warm hotspot complicated by cool hotspot (propane), shell emission

To settle if high-Z gas improves inner beam propagation, need to compare implosions with good symmetry throughout time

Time-varying $\Delta \lambda$ or cone fraction may be needed - warm and cryo

Should check symmetry and strength of warm first 3 shocks - keyhole or re-emit shot
Other relevant presentations – all before this one!

Tent and shape:
O. Jones, IFSA 2013
S. Nagel, Wed. AM, NO4.00014
S. Haan Tues. PM, JO7.00001

Low-mode asymmetries:
A. Kritcher Wed AM NO4.00004
R. Town Wed PM QI3.00002

Inline SRS Hydra modeling:
M. Marinak, Wed. AM, NP8.00090
Overall reflectivity slightly lower on warms. Pure $\Delta \lambda$ scaling, or gas fill effect?
P2 shape: positive for sausage (prolate), negative for pancake (oblate)

Equatorial X-ray Detector:

In-flight shell images shot N130509

Hotspot images shot N130405
• **Nuclear:** Deuterated propane $\text{C}_3\text{D}_8 \rightarrow$ up to $2.6\times10^{11}$ neutrons, $T_{\text{ion}}$ up to 1.7 keV
But: 2D ConA shots show warms have large in-flight pancake, cryos had in-flight sausage

Red: warm
Blue: cryo
☐: $L_{hohl}$ -300 µm
✚: $L_{hohl}$ +700 µm

$P_0 = \text{radius}$

$P_2 = \frac{P_2}{P_0}$

- sausage
- pancake

No shape data

Hotspot ~ 50 µm
Outer beam SBS: DrD sensors show more on cone 50 than 44, and give power scaling.

- DrD = drive diagnostic sensor - at least one beam in each quad
  - $3\omega$ power history - forward and backward (separated in time)
  - N130125: one quad on each cone had 18% higher power: power scaling on one shot!

- Why more SBS on 50’s than 44’s?
  - 50 focal spot smaller -> higher intensity
  - Cross-beam energy transfer calculations: post-transfer power on 50’s > 44’s
  - Could be pure intensity scaling; plasma conditions may also play role

N130125: 970 kJ shot
SBS on 50° outer cone

- Cryo shots show some outer SBS late in time, esp. for longer pulses or high power
- Warm platform good for studying outer SBS and mitigation – cheaper, reproducible
Warm radius slightly larger: cooler hotspot, shell emission?

N130627: 0.5x capsule fill pressure

\( P_0 \) [\( \mu m \)]

\( \lambda_{in} - \lambda_{out} \) [Å]