Cross-Beam Energy Transfer (CBET) and Stimulated Brillouin Scattering (SBS) in NIF Hohlraums

Talk CO6.3
APS DPP 2018
Portland, OR, USA

CBET and SBS on NIF

CBET transfers power to laser with longer wavelength in plasma rest frame (Doppler shifted by flow)

NIF cone wavelengths = “colors”, $\Delta\lambda$.
- Current: 23°, 30°, outers $\rightarrow$ “3 colors”
- Summer 2019: 44° and 50° separate $\rightarrow$ “4 colors”

• High-fill hohlraums: 2009 – 2014
  - Large $\Delta\lambda$: CBET to inners
    - Needed for round implosion
    - Overcome absorption, Raman scattering

• Low-fill hohlraums: 2013 – present
  - Usually $\Delta\lambda = 0$ for round implosion
  - Outer SBS at end of pulse, esp. on 50’s
CBET can occur in low-fill hohlraums with or without $\Delta \lambda$, could mitigate $50^\circ$ SBS

CBET without $\Delta \lambda$:
Bigfoot shots on NIF

- CBET modeling: VAMPIRE code
- CBET swings: to inners early, outers late

Inner power: $23 + 30$

Reduce $50^\circ$ SBS

$\lambda_{44} > \lambda_{\text{in}} > \lambda_{50}$

Goals:
- CBET from 50’s, to 44’s
- Same inner power
  $\rightarrow$ Same implosion shape

Symmetric $\Delta \lambda$

$\Delta \lambda_{44} = +0.5 \text{ A}$

- 50’s to 44’s
- Reduce inner power
  $\rightarrow$ pancaked shape

Asymmetric $\Delta \lambda$

$\Delta \lambda_{44} = +0.25 \text{ A}$

- 50’s to 44’s
- Same inner power
  $\rightarrow$ round shape

$\lambda_{\text{in}}$

$\Delta \lambda_{50} = -0.5 \text{ A}$

$\lambda_{44} > \lambda_{\text{in}} > \lambda_{50}$
Δλ = 0 and low fill can have CBET: “inline” modeling

Lasnex simulations of NIF “BigFoot”\textsuperscript{1} shots
- O. Jones, CO6.9 – later this session
- Used for VAMPIRE modeling

Inline Lasnex CBET model\textsuperscript{2}:
significant CBET to outer beams

Hotspot x-ray shape

Sim f=0.02, no CBET
Sim f=0.02, with CBET
Experiment

1 C. A. Thomas, APS-DPP 2016;
K. L. Baker et al., PRL 2018
2 D. J. Strozzi et al., PRL 2017
VAMPIRE\textsuperscript{1} CBET Code

VAMPIRE: Voronoi Adaptive Method for Propagation and Interaction of Radiated Energy

\textsuperscript{1}A. Colaitis, T. Chapman, D. Strozzi, L. Divol, P. Michel, Phys. Plasmas 2018

- Steady-state in time
- Ray tracing w/ refraction: $\frac{dr}{d\tau} = p, \quad \frac{dp}{d\tau} = \frac{c^2}{2} \nabla \epsilon'(r)$

\begin{itemize}
  \item Intensity evolution
    \begin{itemize}
      \item Inv. brem. absorption
      \item CBET: linear kinetic, strong damping limit
    \end{itemize}

    \[
    \partial_z I_n = - (\kappa_n + \Gamma_n) I_n, \\
    \Gamma_n = \sum_{i \neq n} g_{ni} I_i
    \]

  \item Each quad treated as one unpolarized laser
  \item Polarization and phase neglected in this talk
    \begin{itemize}
      \item Could be important: P. Michel, talk JO6.5 Tues PM
    \end{itemize}

  \item Saturation clamp: $\delta n_e / n_e = 0.01$
  \item SSD and Dewandre effect available
\end{itemize}
$\Delta \lambda = 0$: CBET first to inners, then to outers

![Graphs showing incident power, final power, and inner power](N170418)
Adding $\Delta \lambda$: Redshifting just the 44’s gives more CBET than redshifting just the 50’s

Single-cone $\Delta \lambda$
- $\Delta \lambda$ on just 44’s or 50’s
- Not yet possible on NIF – summer 2019
- $\Delta \lambda > 0$: CBET *TO* one outer cone

- $\Delta \lambda = 1\text{–}2 \text{ Å} \rightarrow$ significant CBET
- Inners + 44’s interact more than inners + 50’s
- 44’s and 50’s NOT equivalent for implosion shape

$\Delta \lambda_{44} = 1 \text{ Å}$
$\Delta \lambda_{50} = 1 \text{ Å}$

Inner power: $23 + 30$

N170418
Symmetric $\Delta \lambda$: $\lambda_{44} > \lambda_{\text{in}} > \lambda_{50}$: $50^\circ$ SBS mitigation, but inner power reduced.

44’s vs. 50’s: CBET from 50’s, to 44’s

Inners vs. Outers: Inner power reduced, shape changed

$\Delta \lambda_{44} = +1 \text{ Å}$
$\Delta \lambda_{50} = -1 \text{ Å}$
Asymmetric $\Delta \lambda$: $\lambda_{44} > \lambda_{in} > \lambda_{50}$: 50° SBS mitigation, and inner power same

44's vs. 50's: CBET from 50's, to 44's

Inners vs. Outers: Inner power same, shape same

Incident post CBET, $\Delta \lambda = 0$

Post CBET, $\Delta \lambda$ asym

$\lambda_{23}, \lambda_{30}$

$\Delta \lambda_{44} = +0.5 \text{ Å}$

$\Delta \lambda_{50} = -1.5 \text{ Å}$
Conclusion: CBET occurs in low gas fill hohlraums, with or without $\Delta \lambda$

Bigfoot shots on NIF: $\Delta \lambda = 0$
CBET to inners early, outers late

- Inner power: 23 + 30

Future work
- Polarization and phase of each NIF beam
- Understand and mitigate CBET and SBS on beams within a quad

Mitigate 50° SBS: asymmetric $\Delta \lambda$
- CBET from 50’s, to 44’s
- Same inner power $\rightarrow$ same implosion shape

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Future work
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50’s power decreases: move down to “sweet spot”
BACKUP BELOW
Δλ = 0 and low fill can have CBET

Lasnex simulations of 2017 NIF “BigFoot” shots
• O. Jones, talk CO6.9 – later this session
• Low e-flux limit f = 0.02

Inline Lasnex CBET model: significant CBET to outer beams

Hotspot x-ray shape

CBET moves toward data

CBET moves away from data

shot index [date]

Experiment
f=0.02 no CBET
f=0.02 inline CBET

1 C. A. Thomas, APS-DPP 2016; K. L. Baker et al., PRL 2018
2 D. J. Strozzi et al., PRL 2017

replace w/ hotspot images. Sims vs. expt
**Δλ = 1 Ang. and low fill: significant CBET to inner beams measured**

“Hybrid C” NIF campaign:
- CH capsule
- Hohlraum fill 0.6 mg/cc

**Hotspot x-ray self emission**

Δλ = inners - outers

- Δλ = 0 Å: Pancaked
  - P0 = 55 μm
  - P2/P0 = -30%
  - Y_n = 8.2E10
  - T_{ion} = 1.65 keV

- Δλ = 1 Å: Sausaged
  - P0 = 59 μm
  - P2/P0 = +17%
  - Y_n = 1.5E11
  - T_{ion} = 1.85 keV

**Δλ at least as effective as in older, high gas fill hohlraums.**
- Partly due to lower inner-beam SRS

This talk:
Δλ quoted at “1ω”:
Δλ = 1 Ang. →
Δλ/λ = 1 / 10528 = 9.5E-5

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1A. Kritcher et al., PRE (accepted)
CBET vs. space: early peak power: 5.0 ns

Outers

Inners

CBET to inners

CBET to cone

Cum. power: CBET to cone

n_e/n_c capped at 0.25 at y=0.0 cm

Local power: absorption + CBET
SSD and Dewandre Effect

- **SSD**: smoothing by spectral dispersion $\rightarrow$ bandwidth:
  - Very slight CBET reduction

- **Dewandre effect**: frequency change due to $\partial n_e / \partial t$:
  - Slight increase of effective inner-beam wavelength
  - More CBET to inners

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Isolate effect of $\Delta \lambda$: $P_{\text{CBET}}(\Delta \lambda \neq 0) - P_{\text{CBET}}(\Delta \lambda = 0)$

Step 2: symmetric outer 3-color:
- $\Delta \lambda_{44} = -\Delta \lambda_{50} = X$

\[\Delta \lambda_{44} = +X, \quad \Delta \lambda_{50} = -X, \quad X = 0.25 \, \text{A}, \quad 0.5 \, \text{A}, \quad 1.0 \, \text{A}, \quad 2.0 \, \text{A}\]
NIF BigFoot shot N170418: $\Delta \lambda = 0$

**Backscatter**
- Mostly 50° SBS late
- Some 23° SBS early

![CBET power graph with higher $\theta$](chart)

![23° backscatter graph](chart)

![30° backscatter graph](chart)
Mitigate 50° SBS: $\lambda_{44} > \lambda_{in} > \lambda_{50}$: CBET from 50’s to 44’s, maintaining cone fraction

Plots are net CBET to 44 and 50, from all other cones

**Base case: $\Delta\lambda=0$**

Post CBET cone frac: 28.2%

**Case A: $\Delta\lambda_{44} = +0.5$ Ang.**

Post CBET cone frac: 26.6%

$\Delta$CBET from $\Delta\lambda$: -1.6%

**Case B: $\Delta\lambda_{50} = -0.5$ Ang.**

Post CBET cone frac: 29.0%

$\Delta$CBET from $\Delta\lambda$: +0.8%
CBET to inners then outers, integrates to ~0

<table>
<thead>
<tr>
<th>CONE</th>
<th>Incident energy [kJ]</th>
<th>CBET energy / incident [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>237.4</td>
<td>0.1</td>
</tr>
<tr>
<td>30</td>
<td>235.2</td>
<td>-1.6</td>
</tr>
<tr>
<td>44</td>
<td>595.9</td>
<td>-2.2</td>
</tr>
<tr>
<td>50</td>
<td>588.4</td>
<td>+4.2</td>
</tr>
</tbody>
</table>

cone frac: inner / total [%] = 28.5
post CBET