Stimulated Brillouin Scattering in Long-Scale-Length Plasmas

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SBS in the present long-scale-length experiments saturates ~1% and is now reasonably understood

- OMEGA long-scale-length experiments have flat velocity regions similar to the NIF.

- SBS is observed in these regions. Pf3d simulations and standard SBS gain calculations agree well with observations.

- SBS extrapolation to NIF direct-drive implosion experiments predicts no problems in the low-density region.

- The detailed NIF and OMEGA plasma profiles differ near $n_c$.
  - Velocity gradients near $n_c$ are steeper in OMEGA experiments.
  - NIF SBS gains near $n_c$ are higher due to gentler density and velocity gradients.
  - More detailed analysis is required.
Motivation

NIF direct-drive plasma conditions predicted by LILAC point toward a window of SBS vulnerability

\[ \alpha = 3 \]
OMEGA long-scale-length conditions are tailored to reproduce NIF conditions.

SAGE predictions for OMEGA long-scale-length experiments are close to NIF conditions below $n_c/4$. 

![NIF density profile at 6.2 ns](image-url)
OMEGA long-scale-length velocity profiles have flat sections like NIF profiles but over much shorter distances.

Comparison of LILAC NIF plasma conditions at 6.2 ns with OMEGA long-scale-length experiments as predicted by the 2-D code SAGE.
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Comparison of *LILAC* NIF plasma conditions at 6.2 ns with OMEGA long-scale-length experiments as predicted by the 2-D code *SAGE*.

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Comparison of \textit{LILAC} NIF plasma conditions at 6.2 ns with OMEGA long-scale-length experiments as predicted by the 2-D code SAGE.
NIF plasma conditions are produced on OMEGA with staggered multiple-beam irradiation of solid CH targets.

- **Nine plasma-producing beams (P)** at –2.5 ns, 1.5-mm diam
- **Eight heater beams (S)** at 0 ns, 1.5-mm diam
- **Interaction beam (I)** (BL25) at 0 ns

The image also includes a graph showing pulse shapes with normalized power on the y-axis and time (ns) on the x-axis. The graph indicates three labeled points: P, S, and I, corresponding to different beam types.
SBS at normal incidence with a slowly evolving velocity “bump” exhibits blue-shifted SBS over the entire pulse that is sensitive to beam smoothing.

\[ I \approx 5 \times 10^{14} \text{ W/cm}^2 \]

**SAGE run 3261**

- **Density** \( (n_e/n_c) \)
- **Distance** (mm)
- **Expansion velocity** \( (10^7 \text{ cm/s}) \)

**Wavelength** (nm)

- 352.0
- 351.5
- 351.0
- 350.5

- 20836, \( 8 \times 10^{14} \text{ W/cm}^2 \), 0.5-THz SSD, PS

- **Inc. laser**
- **SBS25**
- **Density**
- **Expansion velocity**
- **Distance** (mm)
- **Time** (ns)

4.2%
Multiple interaction beams at oblique incidence allow the identification of optical seeding of SBS

- Beam 30 only avoids EM seeding from any speculally reflected light.
- Beam 14 only provides specularly reflected light.
- Firing both beams permits the study of EM seeding of SBS.
NIF plasma conditions are reasonably well approximated by OMEGA experiments for $n_e < n_c/4$.

$LILAC$ prediction for NIF at 6.8 ns ($\alpha = 3$)

- Sonic point
- NIF region of SBS vulnerability

![Graph showing density and temperature profiles vs radius](image-url)
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$I = 1.5 \times 10^{15}$ W/cm²
SSD, 1 THz, PS

SAGE run 3268

Density ($n_e/n_c$)

Distance (mm)

Expansion velocity ($10^7$ cm/s)

Wavelength (nm)

FABS

SBS30

Distance (mm)

Time (ns)

I ≈ $1.5 \times 10^{15}$ W/cm²
SSD, 1 THz, PS
The fast-evolving velocity bump leads to early quenching of the blue-shifted SBS feature while the EM-seeded red feature disappears without seed.

\[ I \approx 1.5 \times 10^{15} \text{ W/cm}^2 \]

SSD, 1 THz, PS

SAGE run 3268

No opposing beam (no seeding by specularly reflected beam)
Standard SBS gain predictions* for OMEGA long-scale-length plasma experiments agree very well with observations.

SBS gain for peak (average) intensity = $8 \times 10^{14}$ W/cm$^2$
(saturated inside high-intensity speckles of 3 to 5× average intensity)

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Low SBS gain is easily observed in the presence of an opposing beam. (EM seed amplified by SBS gain)

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\[ 20836, 8 \times 10^{14} \text{ W/cm}^2, \]
\[ 0.5\text{-THz SSD, PS} \]

\[ \text{Log}_{10}(I) \]
\[ \lambda \]

\[ \text{Maximum gain } \sim 8 \]
\[ \text{Inside speckle peaks maximum gain } >20 \rightarrow \text{saturation broadening expected} \]

\[ \text{E13886} \]

LPI simulations confirm SBS growth from thermal noise in the underdense region

- Velocity bumps are responsible for significant SBS gains.

- Pf3d and standard SBS gain calculations* using SAGE predictions for the plasma correctly predict the measured SBS blue shifts and gains.
  - Standard SBS gains are consistent with observations when speckle intensities are included (growth from thermal noise).

- Gain of the red-shifted SBS component is much lower, but EM seeding makes it easily observed.

SBS gain predictions for the NIF quad are similar to OMEGA in low-density corona; high-density SBS may be higher on the NIF.

\[
S_{\text{SBS}}(\lambda, \omega, t) = I_n(\omega) \exp(G(t)I_{\text{inc}}) \alpha
\]

\[
\Rightarrow \text{more detailed analysis required}
\]

EM-seeded SBS
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