Stimulated Raman Scattering in Direct-Drive Inertial Confinement Fusion

Experiments carried out at the National Ignition Facility

View ports

FABS

50°

30°

23°

Laser power (arbitrary units)

Time (ns)

0 2 4 6

Plasma-producing beams ("outer")

Interaction beams ("inner")

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Absorption and refraction significantly affect stimulated Raman scattering (SRS) in National Ignition Facility (NIF) planar-target experiments

- Planar NIF experiments are SRS dominated

- SRS spectra are strongly affected by absorption and refraction
  - are predominantly caused by sidescattering
  - coronal $T_e$ predictions match measurements using spectroscopy

- Estimates of total SRS levels ~5% of incident are based on simulations, ray-trace calculations, a few measurements, and large extrapolations
Collaborators


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$\omega/2$ light (702 nm) from absolute SRS can escape at $\leq 18^\circ$ from $\nabla n$ although with rapidly decreasing efficiency

- Absorption of $\omega/2$ light is high (>97%)
- Refraction severely limits the angular emission of $\omega/2$ light
- Only a tilt of the target allows for $\omega/2$ light to be observed at NIF ports

CH target

Q33 SRS diagnostic

17 NIF quads at 0° to 55° to target normal

$T_e$ (keV)

$\lambda$ (nm)

Distance (mm)

Time (ns)

Distance (mm)

$527$ nm

$500$ nm

$n_c/4 \rightarrow$

$M = 1$
The total absolute SRS emission can be estimated from ray trace and simulated plasma conditions

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- Refraction severely limits the angular emission of $\omega/2$ light
- Only a tilt of the target allows for $\omega/2$ light to be observed at NIF ports

\[ I(\theta) = T_0 \times \exp \left[-\left(\frac{\theta}{10.5}\right)^6\right] \]

\[ T_0 = 2\% \]

\[ \text{Multiplier } -2230 \] for tilted target

\[ \lambda \text{ (nm)} \]

\[ \theta (\degree) \]

\[ T_e \text{ (keV)} \]
\( \omega/2 \) spectra in OMEGA implosions are a signature of two-plasmon decay (TPD), while on the NIF they represent the absolute SRS instability.

The sharp, red-shifted spectral signature is a useful coronal temperature diagnostic. Measured and DRACO-predicted electron temperature agree very well.

- TPD-related photons require an inefficient generation mechanism.
- Every SRS decay results in a scattered photon (100% efficiency).
- Absolute SRS may effectively suppress TPD.
Theory supports that NIF planar experiments are SRS-dominated, while the OMEGA experiments are TPD-dominated.

TPD threshold depends on $T_e$; SRS threshold does not*.

702-nm photon escape: ~2%
630-nm photon escape: ~50%

* R.W. Short, based on single-beam theory (private communication).
SRS spectra observed at $23^\circ$, $31^\circ$, and $50^\circ$ indicate that SRS sidescattering dominates over backscattering.

- $\sim 50\%$ of the incident laser radiation reaches SRS densities with minimal refraction.
- SRS light is significantly affected by refraction, particularly at $\lambda > 650$ nm.
- For incident laser at $30^\circ$, local SRS sidescattering at $>30^\circ$ is required.
The total SRS emission can be estimated from measurements and simulations

- Estimates of total SRS energy of ~5% of incident (CH target shot 160406) and
  - measured SRS energies (fast diodes)
  - measured spectra
  - assuming sidescattering as deduced from ray trace using DRACO plasma parameters

Because SRS energy measurements are restricted on the NIF to two (non-optimal) locations, the extrapolations are problematic but still useful.
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- Estimates of total SRS levels $\sim$5% of incident are based on simulations, ray-trace calculations, a few measurements, and large extrapolations
$\omega/2$ spectral shifts can be used for coronal $T_e$ measurements

NIF planar-target experiments ($\omega/2$ spectra)

Draco
4.5 keV

702 nm

CH target

$\Delta \lambda_{nm} = 3.09 * T_e, \text{keV} - \delta \lambda_{\text{Doppler}} - \delta \lambda_{\text{Dewandre}}$

Stationary plasma
Plasma flow
Diverging plasma