Modeling Laser-Plasma Interactions in MagLIF Experiment on NIF

Anomalous Absorption Meeting

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MagLIF shot on NIF gave excellent laser propagation and good agreement with modeling

MagLIF NIF Target
(View from GXD x-ray camera)

Tantalum witness plate

Laser entrance hole + window (0.75 um thick polyimide)

10.75 mm

8.9 mm

Plastic gas pipe
Neopentane
C₃H₁₂ fill

Quad Q16B

Quad Q31B

Focused at pipe center

This talk:
shot N160128
Repeat, better diagnostics: N160425

B. Pollock, R2-1:
Prior talk
More on expts

Successfully demonstrated laser propagation
at MagLIF fusion-gain scale
Summary: MagLIF NIF shots modeled with rad-hydro and LPI codes

Modeling tools
- **HYDRA**: ICF radiation-hydrodynamic code
  - Agrees with laser propagation down tube
  - Provides plasma conditions for LPI modeling
- **Gain spectrum**: linear gain exponents integrated along laser rays
  - 1D, linear, kinetic, fast – no speckles, filamentation, nonlinear kinetics
- **pF3D**: paraxial envelope propagation code
  - Massively parallel, 3D NIF-relevant volumes [R. Berger, S. Langer - Tuesday]

**SRS**: peak reflectivity ~ 0.3%, from fill gas
- Measured and gain spectra: close, contain two distinct wavelengths
- pF3D: two SRS wavelength groups: dominant one agrees with data

**SBS**: Peak reflectivity ~ 3% when laser hits Ta plate
- Gain spectrum close to data, but gain from gas not Ta
- pF3D modeling ongoing
MagLIF NIF shot follows standard NIF “warm” (293 K) surrogacy approach

**NIF TARGET**
- Gaspipe: 1 cm long, 1 cm diameter
- Thin window: 0.75 um polyimide
  - Use same warm and cryo
- MagLIF D$_2$ fill breaks window @ STP
- Use large hydrocarbon: match $n_e$
- Fill: neopentane C$_5$H$_{12}$ @ 1 atm.
  - $n_e = 0.116 \ n_{crit}$ fully ionized
  - Same $n_e$ as D$_2$ at 3.5 mg/cm$^3$
- No imposed B field: 10-20 T in 2017?

$$\frac{n_e}{n_{crit}} \ @ \ 8.5 \ nm \ [HYDRA \ sim.]$$

**NIF LASER: well-conditioned**
- Wavelength: 351 nm “3$\omega$”
- One 30° cone quad (4 beams) – Q31B
- Nominal phase plates, F=8 for quad
- “Checkerboard” polarization smoothing
- SSD: 45 GHz
- Focal spot: ellipse, radii (824, 590) um

**Laser pulse**
- 10 ns peak power:
  - 3 TW $\rightarrow$ 1.6*10$^{14}$ W/cm$^2$
- 2 ns “toe”: burn down window
Low power and intensity gave low backscatter, some SBS when laser hits Tantalum plate.

- Laser hits Ta plate at 10 ns – close to x-ray camera data
- Additional backscatter on NBI plate outside of lens ~ few *FABS: analysis ongoing
SRS data and gain spectrum qualitatively similar before 10 ns

- Main feature moves to shorter wavelength with time $\rightarrow$ lower $n_e$
- Longer wavelength feature appears late in time
Plasma conditions from HYDRA run at 8.5 ns: peak measured SRS

HYDRA run:
- No MHD
- f=0.05 electron heat flux limit
- DCA non-LTE atomic physics
SRS at 8.5 ns: two features in data and gain spectrum

SRS matching
\[
\begin{align*}
\lambda_{\text{SRS}} \text{ [nm]} & & T_e \text{ [keV]} & & n_e/n_{\text{crit}} & & k_{\text{EPW}} \lambda_{\text{De}} \\
464 & & 1 & & 3.6\% & & 0.40 \\
536 & & 0.5 & & 11.2\% & & 0.14
\end{align*}
\]

$T_e$ chosen from pF3D results
pF3D*: paraxial envelope light propagation code, massively parallel


Light wave vector potential:

\[ \tilde{A}_0(x, t) = \frac{1}{2} \tilde{A}_0(x, t) \hat{p} \exp \left( -\omega_0 t + \phi_0 \right) + cc \]

- Slowly-varying envelope
- Polarization: fixed, in xy plane

Laser envelope equation:

\[
\begin{aligned}
[ \partial_t + v_{g0} \partial_z - i \frac{(c^2/\omega_0) \nabla^2_\perp}{1 + (1 + k_0^{-2} \nabla^2_\perp)^{1/2}} + \nu_0 + i \partial_t \phi_0 + \frac{1}{2} \partial_z v_{g0} ] \tilde{A}_0 & \propto \delta n_{ef} \tilde{A}_0 + \frac{1}{2} \delta n_a \tilde{A}_B + \frac{1}{2} \delta n_l \tilde{A}_R \\
\end{aligned}
\]

- Advection: not strong damping limit
- Diffraction: Feit-Fleck form
- Damping
- DAW phase shift

Envelopes evolved:
- Laser light
- SRS light – 1 or 2 wavelength groups
- SRS Langmuir wave – 1 or 2 groups
- SBS light
- SBS ion wave: no time enveloping

Background hydro w/ ponderomotive force:
- Filamentation
- Cross-beam energy transfer
pF3D “Letterbox” run for backscatter: routine vs. “heroic” 3D run

“Letterbox”: slice in one transverse direction

- Same intensity distribution and speckle statistics as full beam

Laser Intensity in transverse plane

Computing resources

Spatial zoning: $dx = dy = 2 \lambda_0$, $dz = 3 \lambda_0$
Plasma volume $1.9 \text{ mm}^3$
Zones: 3.9 billion
LLNL Sequoia machine: 8192 cpu’s, ~ 1 day

Peak SRS (8.5 ns): pF3D agrees with data: shorter wavelength SRS dominates, SBS small

Reflectivity:
2 SRS groups, and SBS

Measured reflectivity into FABS:
SRS: 0.3%, at 480 nm, << at 540 nm
SBS: noise
Peak SRS: SRS develops at end of laser path

- Time 104 ps
- Intensities on different log scales
- Aspect ratio not unity
Late-time SBS gain spectrum consistent with data

Measured SBS spectrum

SBS linear gain spectrum close to data

Late-time SBS occurs when laser hits tantalum back plate: but where is it coming from?
SBS gain spectra late in time: most gain coming from gas, some at short wavelength from Ta

10 ns
Gain In Ta

11.5 ns

SBS seed in Ta plate, Amplified in gas?
Conclusions and future work

Modeling
• HYDRA correctly gives laser propagation, based on x-ray camera data
• SRS: two wavelengths in gain and data, pF3D gives same dominant one as data
• SBS burst when laser hitting Ta back plate, but gain in gas at that time

Future NIF shots
• Push to higher backscatter risk:
  • Higher intensity
  • Higher fill density
• Cryogenic D_2 fill, thin window: ignition relevant, instead of warm surrogate C_5H_{12}
• Imposed B field: 10-20 T in 2017?

Warm C5H12 fill, no imposed B field:
Successful laser propagation at MagLIF fusion-gain scale

Cryogenic D2 fill, imposed B field:
Will test complete MagLIF scheme – to be done soon...
BACKUP BELOW
SBS shift in high Z plasma:

\[
\delta \lambda [\text{Å}] \approx 7.3 \left( \frac{Z}{A} T_e [\text{keV}] \right)^{1/2} \left( 1 + \frac{\vec{u} \cdot \vec{k}_0}{c_{ac}} \right) \implies 4.9 \text{Å}
\]

Tantalum: \( A=181, \ Z=42 \)

\( T_e = 2 \text{ keV}, \ u=0 \)