Modeling Laser-Plasma Interaction over a Suite of NIF Experiments

Anomalous Absorption Conference


17 June 2017
Summary: towards predictive rad-hydro + laser-plasma modeling

- Same “best current” rad-hydro for all shots\(^1\)
  - O. Jones et al., Phys. Plasmas 2017
  - No per-shot multipliers
  - DCA model
  - Electron flux limit 0.03
  - Cross-beam energy xfer clamp \(\delta n_e/n_e=0.01\)

- New in this work: backscatter
  - DEPLETE: ray-based extension of linear gain
  - pF3D: paraxial-envelope code: speckles, polarization smoothing, SSD, etc.

- NIF “bigfoot” shot
  - CBET (calculated) to outer cones
  - Outer-cone SBS: 10-15% end of pulse
  - Deplete and pF3D: less increase vs. time
  - Both codes: SBS from gold bubble

Continued improvement in both rad-hydro and LPI modeling

Simulations: too much x-ray drive, esp. for long pulses, high fill density
Rad-hydro model: “best current” physics in Lasnex

- **Opacity + EOS**
  - LTE tables for $T_e < T_{\text{crit}}$, non-LTE DCA for $T_e > T_{\text{crit}}$
  - $T_{\text{crit}} = 300$ eV in wall, 50 eV elsewhere
  - DCA models: March 2014
  - Gold: dca_79x5 – improved gold bubble physics
  - Bug: over-emits x-rays with radiation field: H. Scott

- **Laser**
  - Escaping backscatter power removed from incident laser – no inline SRS/SBS
  - Inverse brem. absorption + Langdon effect
  - Inline CBET: unpolarized quads, saturation $\delta n_e/n_e = 0.01$
  - Ponderomotive force: needed for CBET momentum deposition

- **Electron heat conduction**
  - Heat flux $q = \min(q_{\text{SH}}, f n_e T_e v_{Te})$
  - $q_{\text{SH}} = \text{Spitzer-Harm} + \text{Lee-More corrections}$
  - flux limit $f = 0.03$ everywhere
  - No MHD, nonlocal, ion turbulence models

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2D RZ axisymmetric
Only bottom half: BS diagnostics there

FABS, NBI detectors

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$^1$O. Jones et al., Phys. Plasmas 2017
Rad-hydro model: numerics / logistics

• No ad-hoc / per-shot multipliers: power, cone fraction, ...
• LHT (Lasnex Hohlraum Template) version-controlled input deck
  • Needed to handle multiple shots + multiple designers
  • Based on deck from Cliff Thomas, from Richard Town, Peter Amendt, etc.
• Same Lasnex version: 13 April 2017

• **Numerical resolution:** O. Jones’ ”hi-res” settings from convergence study¹
  • Capsule: 72 angular zones in 90° → Δθ = 1.25°
  • Wall: innermost zone Δr=4 nm, Δr increases by 1.03x
  • 180 radiation energy groups
  • 10 zones across LEH window thickness

• **Mesh:** “As Lagrangian As Reasonably Achievable”*
  • ALE (Arbitrary Lagrangian-Eulerian) mesh management: R. Tipton
  • Hohlraum: ALE from t=0, may freeze mesh after laser is off
  • Capsule: ALE from user-determined t>0, mesh not frozen

• **Laser:** 600 rays per quad, CBET iteration options

¹O. Jones et al., Phys. Plasmas 2017
* N. Meezan, private communication (2007)
Energetics across a set of NIF shots

Drive deficit:
- Rad-hydro codes over-predict x-ray drive in NIF hohlraums
- Long-standing issue
- Especially for long pulses, high gas fill density, and high backscatter

![Graph showing measured vs simulated x-ray bangtime](image-url)

- **Bigfoot DT**: 0.3 mg/cc
  - Gas scan: 1.6 mg/cc
    - Long coast time, Higher SRS
- **HDC DT**: 0.3 mg/cc
  - Gas scan: 0.6 mg/cc
Bigfoot

- 1st and 2nd shocks overtake in ablator, before reaching DT fuel
- “Robust” hostspot: high adiabat, lower convergence, high rho*R
- Less prone to hydro instabilities (e.g. Rayleigh-Taylor) and loss mechanisms
- At price of lower 1D gain

\[ \Delta \lambda = 0: \text{CBET due to plasma flow only} \]

“Quad splitting”:

- Spread out outer beam spots on wall
- 4 beams in an outer quad split in azimuth
- 44’s and 50’s separated in Z

Benefits:

- Less azimuthal variation
- Lower intensity \( \rightarrow \) lower SBS
- Less M-band x-rays
- Less wall / bubble motion

\(^1\text{C. A. Thomas, APS DPP 2016 invited talk}\)
Bigfoot shot N170109: SBS late in time on cone 50

Q31B FABS: quad on cone 30

Q36B FABS: quad on cone 50

Drive diagnostic sensors
SBS in >= one beam on every quad:
• More SBS on cone 50 than 44

Cone: 23, 30, 44, 50

noise
Bigfoot: calculated CBET to outers, especially 50’s

From cone 30: transfer TO 44’s and 50’s

Net transfer to each cone

To 50
To 44
To 23

50 inc. / 3
44
23
-30 inc. / 3
30

From cone 50: transfer FROM all other cones

Cone fraction = Inner / Total power

From 44
23
30

-30 inc. / 3
30

NIF Shot
N170109
DEPLETE$^1$: ray-based, steady-state backscatter calculations, extension of linear gain

\[
\frac{d}{dz} I_0(z) = -\kappa_0 I_0 - I_0 \int d\omega_1 \frac{\omega_0}{\omega_1} (\tau_1 + \Gamma_i i_1) - \partial_z i_1(z, \omega_1) = -\kappa_1 i_1 - \Sigma_1 - I_0 (\tau_1 + \Gamma_i i_1)
\]

inv. brem. damping brem. noise Thomson scattering SBS/SRS coupling

DEPLETE gain:
\[
G = \ln \frac{i_1(\omega, z_0)}{i_{1\text{brem}}(\omega, z_0)}
\]

noise level without laser = scattered light with just brem. emission + absorption

Features of DEPLETE:
- Uses 1-D plasma conditions from 3-D ray-trace
- Spectrum of scattered frequencies
- Strong damping limit for plasma waves
- Pump depletion of laser
- Thomson scatter/bremsstrahlung noise sources
- Inverse-bremsstrahlung light wave damping
- Linear kinetic coupling coefficients
- Collisional plasma-wave damping

DEPLETE lacks:
- Temporal effects
- Laser speckles
- PS, SSD
- Dewandre effect
- Multi-D effects, e.g. refractive intensification

Bigfoot: Cone 50 SBS spectrum vs. DEPLETE\textsuperscript{1}

- DEPLETE spectrum redshifted by \sim 2 \text{ Ang.} vs data
- Neglects SSD bandwidth, “Dewandre effect” (wavelength shift due to time-dependent electron density)

Shot N161204 – symcap, has SBS spectrum, analog of DT shot N170109 – no SBS spectrum

DEPLETE: Cone 50 SBS develops in gold bubble

Laser light

SBS light, $\Delta \lambda = 0$ Ang.

SBS light, $\Delta \lambda = 2$ Ang.

Background: $n_e/n_{\text{crit}}$

Laser intensity [a.u.]

SBS intensity / noise [log scale]

N170109
5.75 ns: late peak power
Each ray has narrow SBS resonance at different wavelength\(^1\)

\(^1\)L. Tolstoy, *Anna Karenina* (1878)
Ion waves weakly damped for $ZT_e/T_i \gg 1$: e.g. gold

IAW Landau damping rate: gold

$T_e = 2T_i$, $k\lambda_{De} = 0.6$

\[
\frac{\nu}{\omega} \propto \left(\frac{Zm_e}{m_i}\right)^{\frac{1}{2}} \exp \left[ -\frac{Zm_e}{2m_i} \right] + \frac{1}{2} \left(\frac{ZT_e}{T_i}\right)^{\frac{3}{2}} \exp \left[ -\frac{ZT_e}{2T_i} \right]
\]

Electrons

Ions

SBS spectrum

~$1/\nu$

~$\nu$
Cone 50 SBS: Measured and Deplete reflectivities qualitatively track vs time

Deplete reflectivity: sum over rays of wavelength-integrated SBS intensity
Cone 50 SBS: pF3D$^2$ simulations close to measured reflectivity, when CBET included

$pF3D$ simulations by R. L. Berger


NIF Shot
N170109
pF3D: outer SBS growth localized in gold bubble

- pF3D run includes one 48° and one 52° beam – each orthogonally polarized
- 50° quad has two other beams: spatially separated at wall due to “quad splitting”
- Plots in pF3D coordinates: laser propagates in z
Conclusions and future work

“Best current” rad-hydro model in Lasnex
• DCA 2014 + 79x5 model for gold
• Electron flux limit 0.03
• Inline CBET: saturation clamp $\delta n_e/n_e = 0.01$
• Simulated x-ray flux too high, bangtime early

“Bigfoot” shot N170109
• CBET modeling: CBET to outers, increases in time
• Backscatter: mostly cone 50 SBS, peaks late in time
• Cone 50 SBS modeling: DEPLETE and pF3D
  • Similar reflectivity to data, when CBET included
  • Increase with time less than data

Future work
• Apply to more shots, more LPI data – inner SRS, SBS in beams within quad
• Suggest rad-hydro modeling improvements, e.g. gold bubble
• Use improved rad-hydro models as available