Modeling Laser-Plasma Interactions in MagLIF Experiment on NIF

Anomalous Absorption Meeting

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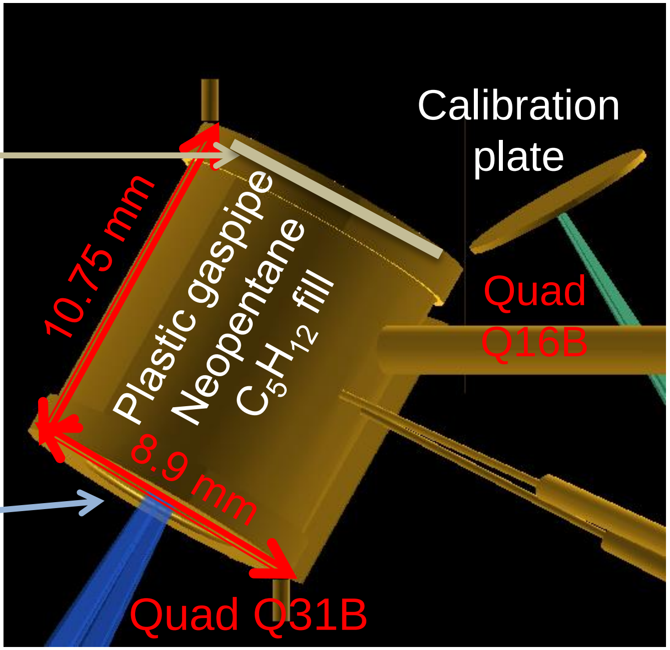
MagLIF shot on NIF gave excellent laser propagation and good agreement with modeling

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



Focused at pipe center

Tantalum witness plate

Laser entrance hole + window (0.75 um thick polyimide)

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

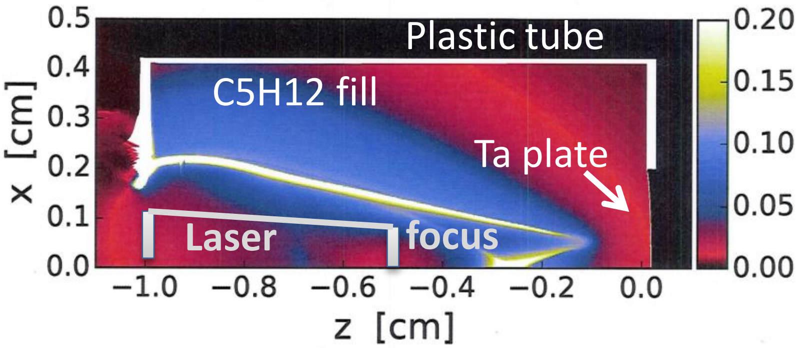
- Gain spectrum close to data, but gain from gas not Ta
- pF3D modeling ongoing

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_5H_{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?

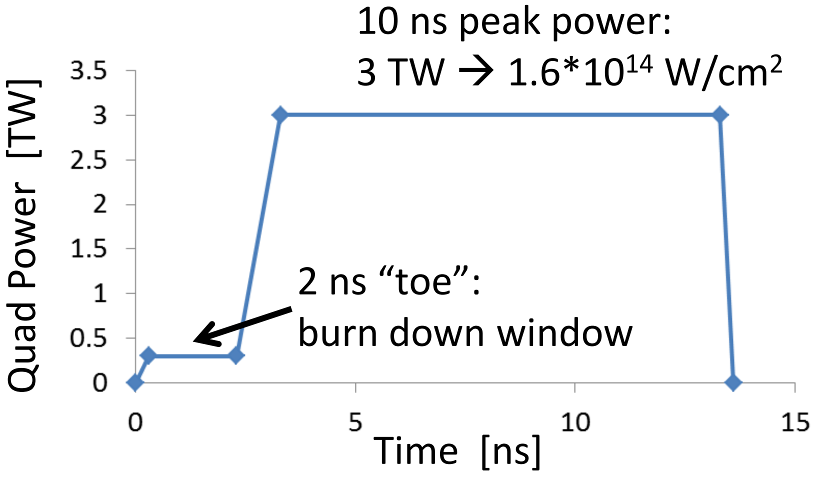
n_e / n_{crit} @ 8.5 ns [HYDRA sim.]



NIF LASER: well-conditioned

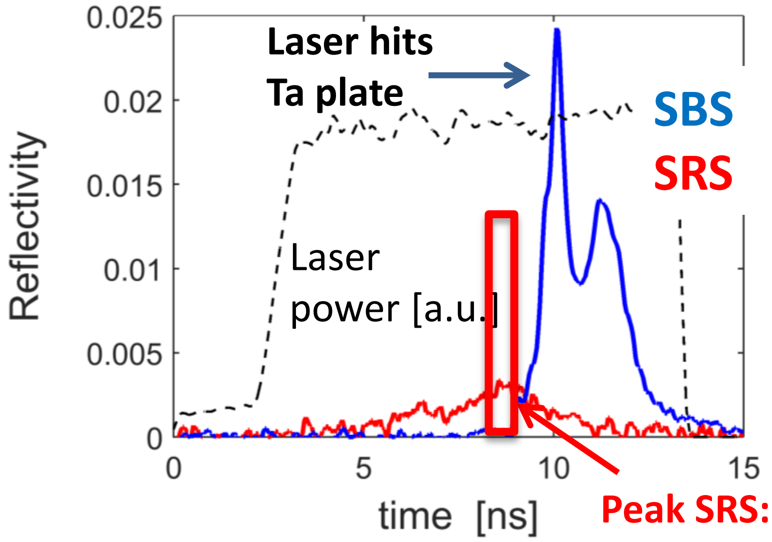
- Wavelength: 351 nm "3ω"
- One 30^o cone quad (4 beams) – Q31B
- Nominal phase plates, F=8 for quad
- "Checkerboard" polarization smoothing
- SSD: 45 GHz
- Focal spot: ellipse, radii (824, 590) um

Laser pulse



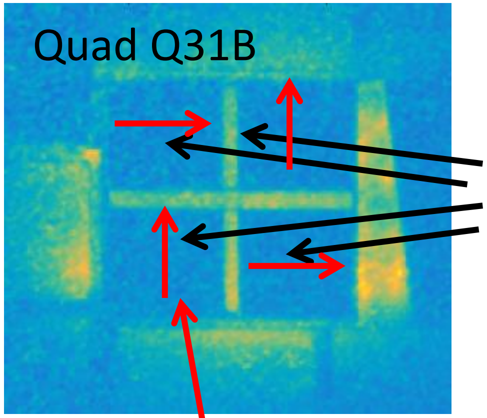
Low power and intensity gave low backscatter, some SBS when laser hits Tantalum plate

Backscatter into FABS detector = lens aperture



Peak SRS: 8.5 ns time of pF3D sims

SRS NBI (Near Backscatter Imager) Image centered on laser ports

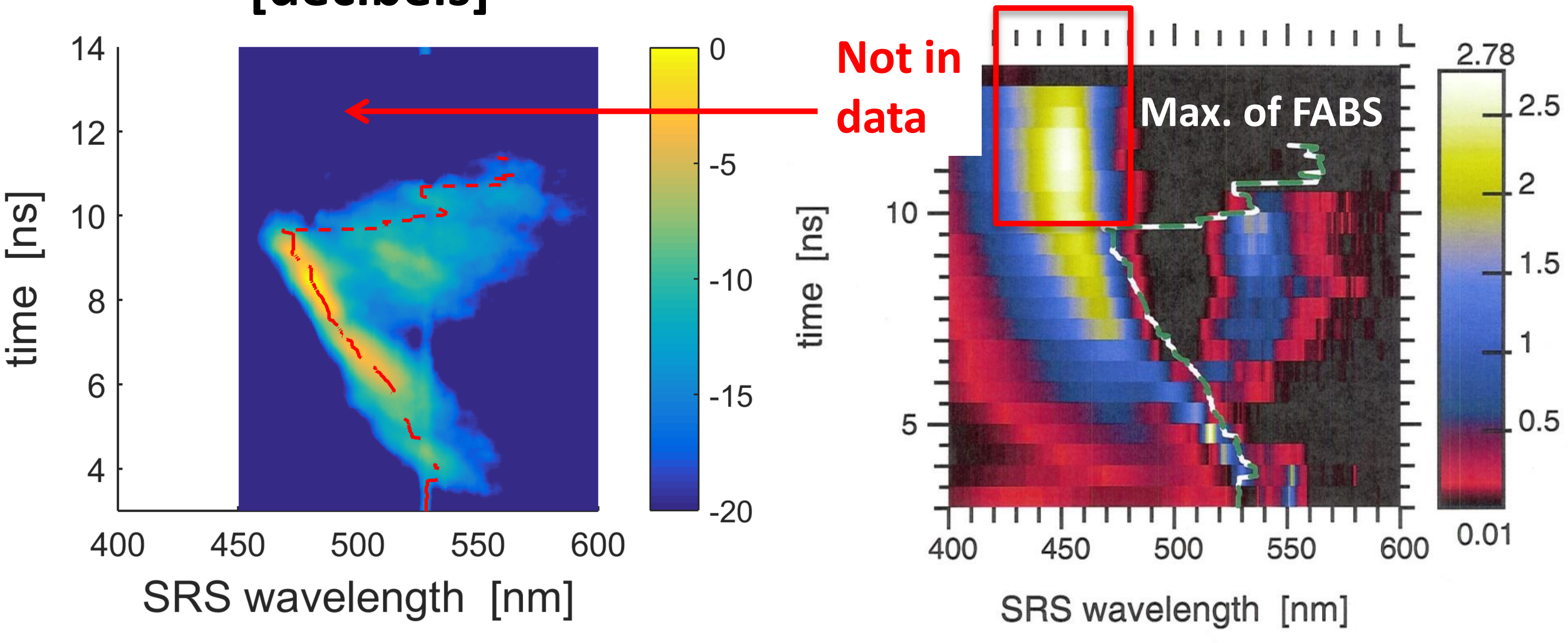


FABS detector in each laser beam port

“checkerboard” polarization smoothing

- 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



Measured SRS spectrum [decibels]

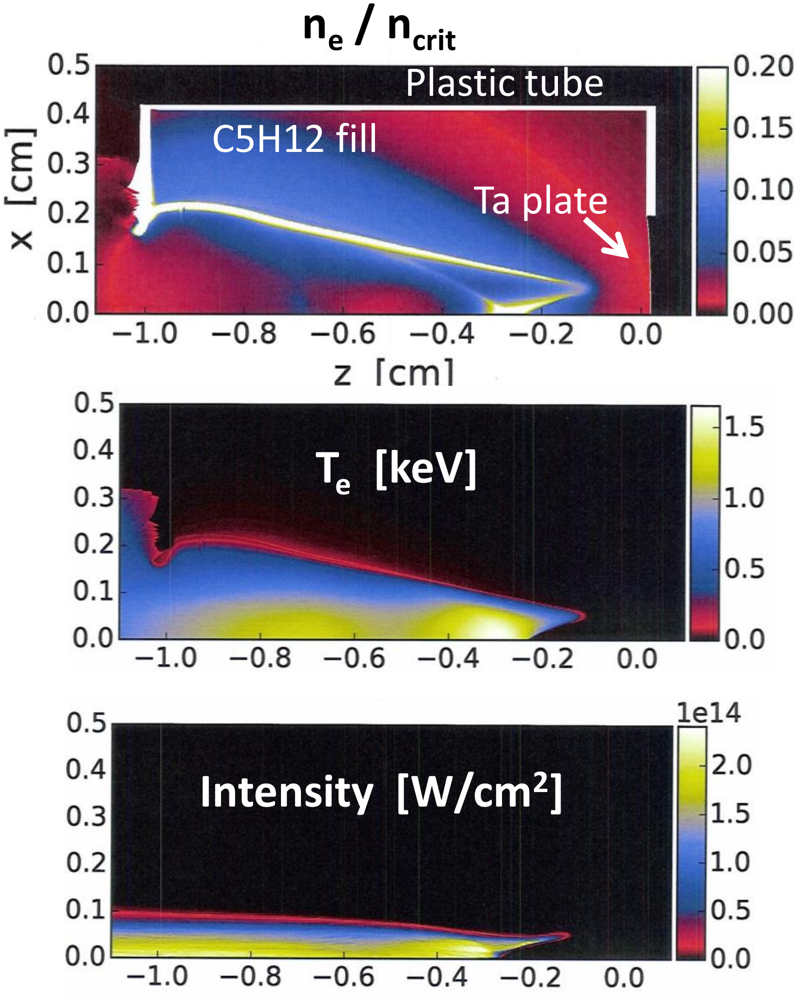
SRS linear gain spectrum

Not in data

Max. of FABS

- Main feature moves to shorter wavelength with time → lower n_e
- Longer wavelength feature appears late in time

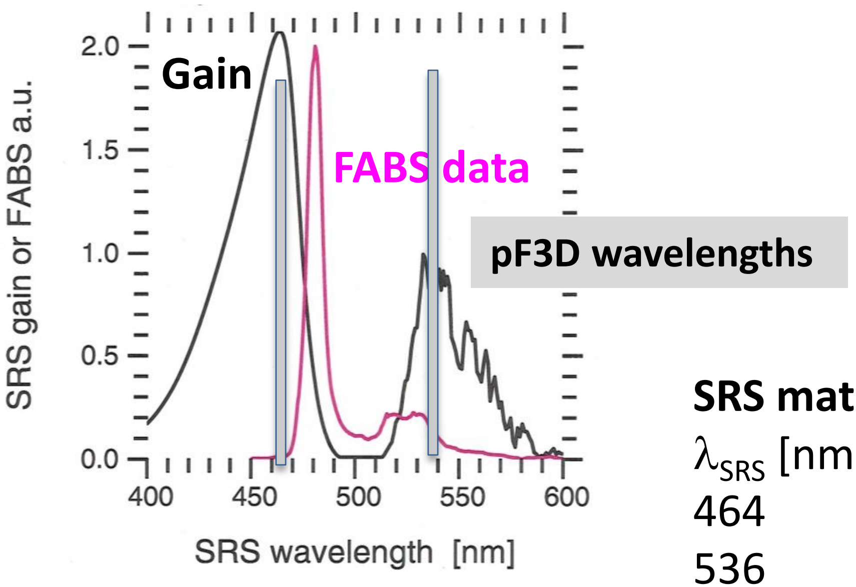
Plasma conditions from HYDRA run at 8.5 ns: peak measured SRS



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

λ_{SRS} [nm]	Te [keV]	n_e/n_{crit}	$k_{EPW}\lambda_{De}$
464	1	3.6%	0.40
536	0.5	11.2%	0.14

T_e chosen from pF3D results

pF3D*: paraxial envelope light propagation code, massively parallel

*R. L. Berger, C. H. Still, E. A. Williams, A. B. Langdon, *Phys. Plasmas* 1998

Light wave vector potential:

$$\vec{A}_0(\vec{x},t) = \frac{1}{2}\tilde{A}_0(\vec{x},t)\hat{p}\exp i(-\omega_0 t + \phi_0) + cc$$

Slowly-varying envelope

Polarization: fixed, in xy plane

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

Laser envelope equation:

$$\left[\partial_t + v_{g0}\partial_z - i\frac{(c^2/\omega_0)\nabla_\perp^2}{1+\left(1+k_0^{-2}\nabla_\perp^2\right)^{1/2}} + \nu_0 + i\partial_t\phi_0 + \frac{1}{2}\partial_z v_{g0}\right]\tilde{A}_0 \propto \delta n_{ef}\tilde{A}_0 + \frac{1}{2}\delta n_a\tilde{A}_B + \frac{1}{2}\delta n_l\tilde{A}_R$$

Advection: ***not*** strong damping limit

Diffraction: Feit-Fleck form

Damping

DAW phase shift

Refraction

SBS

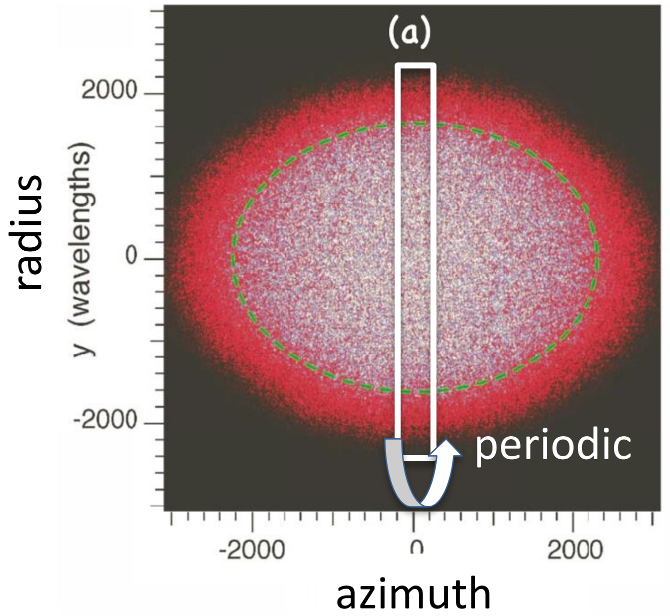
SRS

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

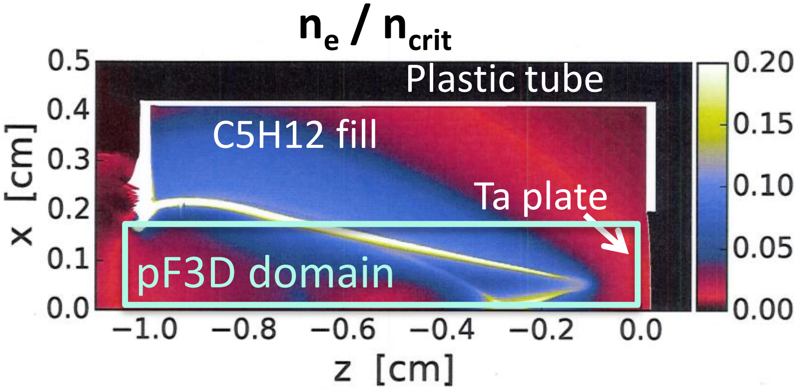


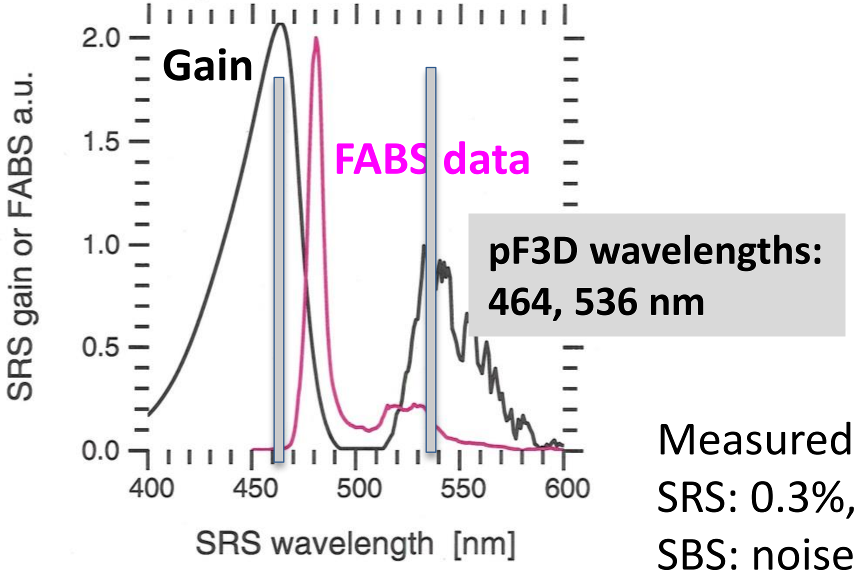
Sample letterbox: D. Hinkel et al., *Phys. Plasmas* 2008

Computing resources

Spatial zoning: dx = dy = 2 λ_0, dz = 3 λ_0
Plasma volume 1.9 mm^3
Zones: 3.9 billion
LLNL Sequoia machine: 8192 cpu’s , ~ 1 day

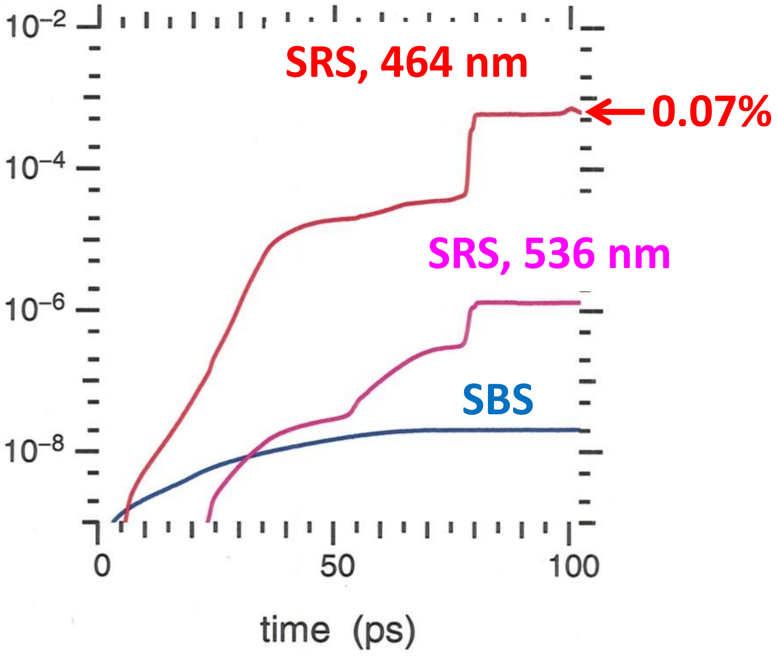
Peak SRS (8.5 ns): pF3D agrees with data: shorter wavelength SRS dominates, SBS small





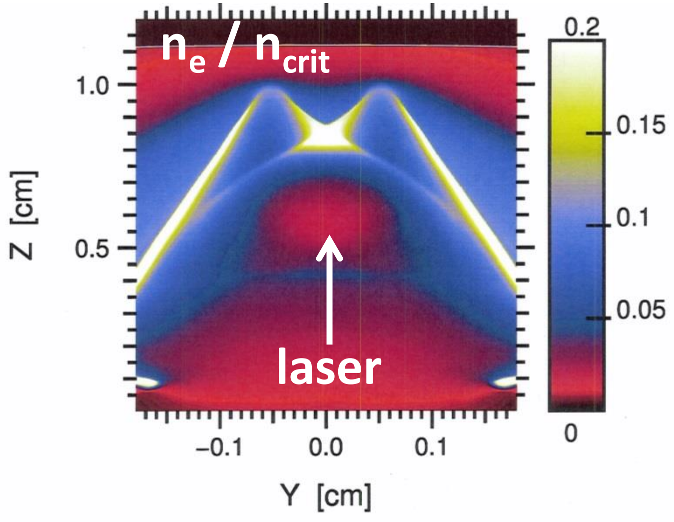
pF3D wavelengths: 464, 536 nm

Reflectivity:
2 SRS groups, and SBS

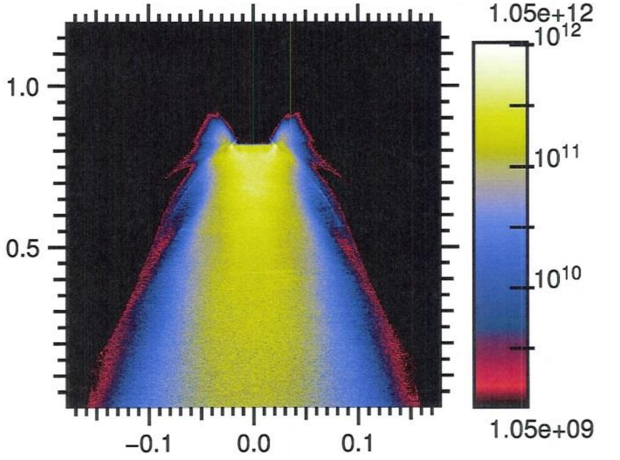


Measured reflectivity into FABS:
SRS: 0.3%, at 480 nm, << at 540 nm
SBS: noise

Peak SRS: SRS develops at end of laser path



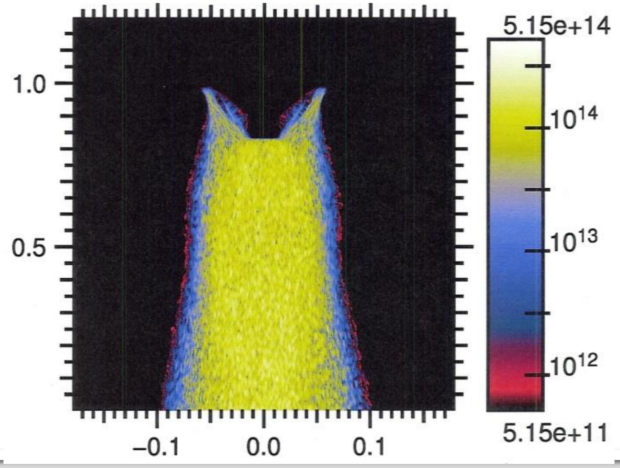
SRS @ 464 nm intensity [W/cm²]



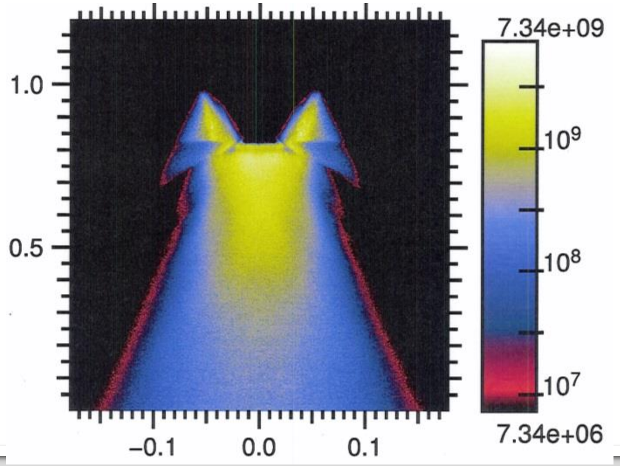
pF3D

- Time 104 ps
- Intensities on different log scales
- Aspect ratio not unity

Laser intensity [W/cm²]

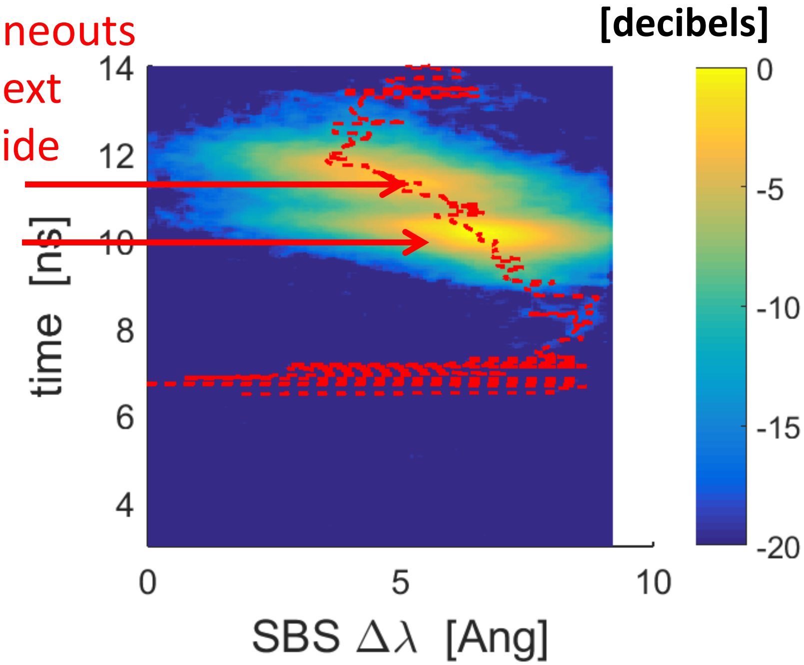


SRS @ 536 nm intensity [W/cm²]



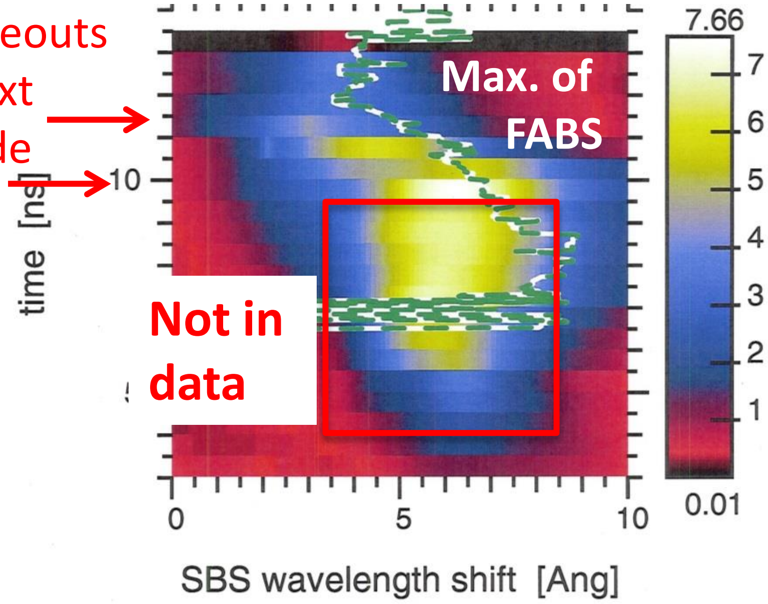
Late-time SBS gain spectrum consistent with data

Measured SBS spectrum



Lineouts
Next
slide

SBS linear gain spectrum close to data



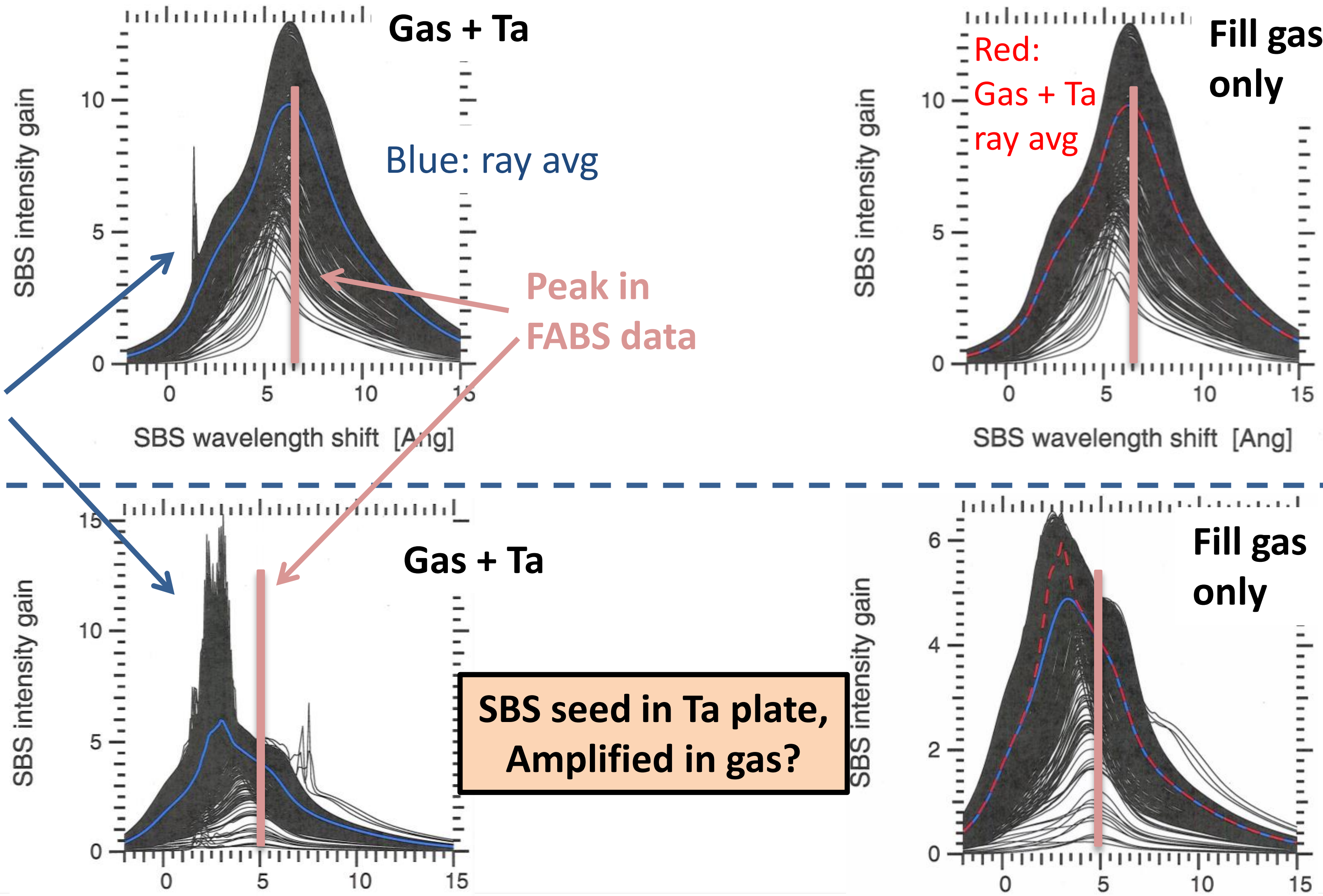
Lineouts
Next
slide

Max. of
FABS

Not in
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

Gas + Ta

Blue: ray avg

Fill gas only

Red: Gas + Ta ray avg

Gain In Ta

Peak in FABS data

11.5 ns

Gas + Ta

Fill gas only

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?

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

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:

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

Tantalum: A=181, Z=42

T_e = 2 keV, u=0

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