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Controlling Stimulated Brillouin Backscatter with Beam Smoothing in Weakly Damped Systems

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Controlling Stimulated Brillouin Backscatter with Beam Smoothing in Weakly Damped Systems

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Anomalous Absorption 2007

NIC

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Motivation: can SSD mitigate outer beam SBS from the high Z wall of indirect drive target designs?

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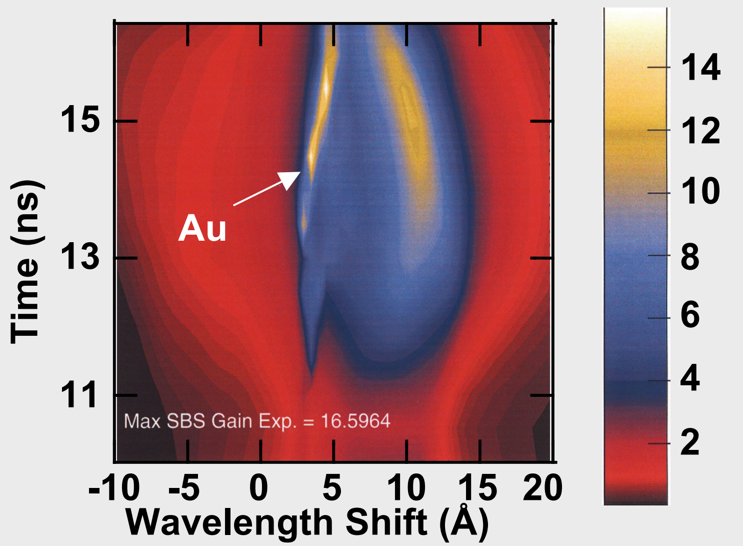
Au wall blow off could be a SBS producer on some NIF point design targets



NIF Design One Target
50 deg. Beam, 1.2 Rev0 Spot

Typical NIF Outer Beam Plasma Parameters

- $I = 4\text{--}7 \times 10^{14}$ W-cm^{-2}
- 200μm Au 10-20% N_{cr}
- Te~Ti ~3-5 keV (in Au)
- G_{sbs} ~ 5-25

As little as 1.5 Å of SSD reduced SBS from the Au wall of NOVA hohlraums

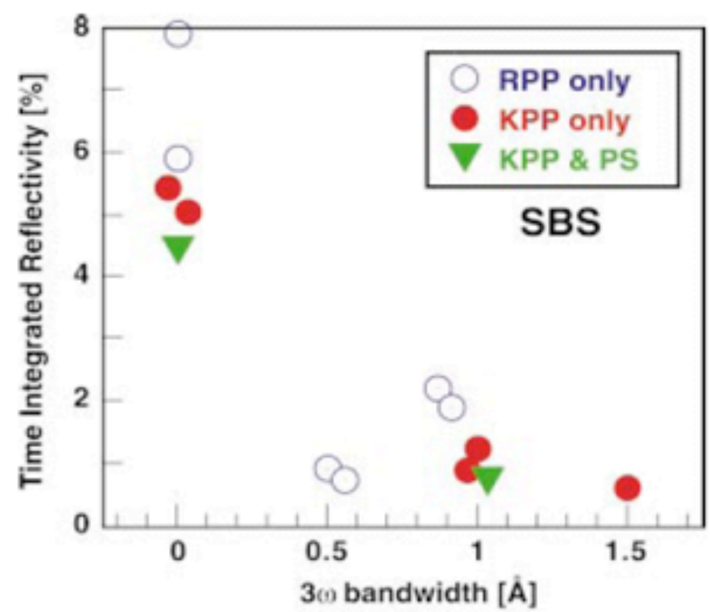
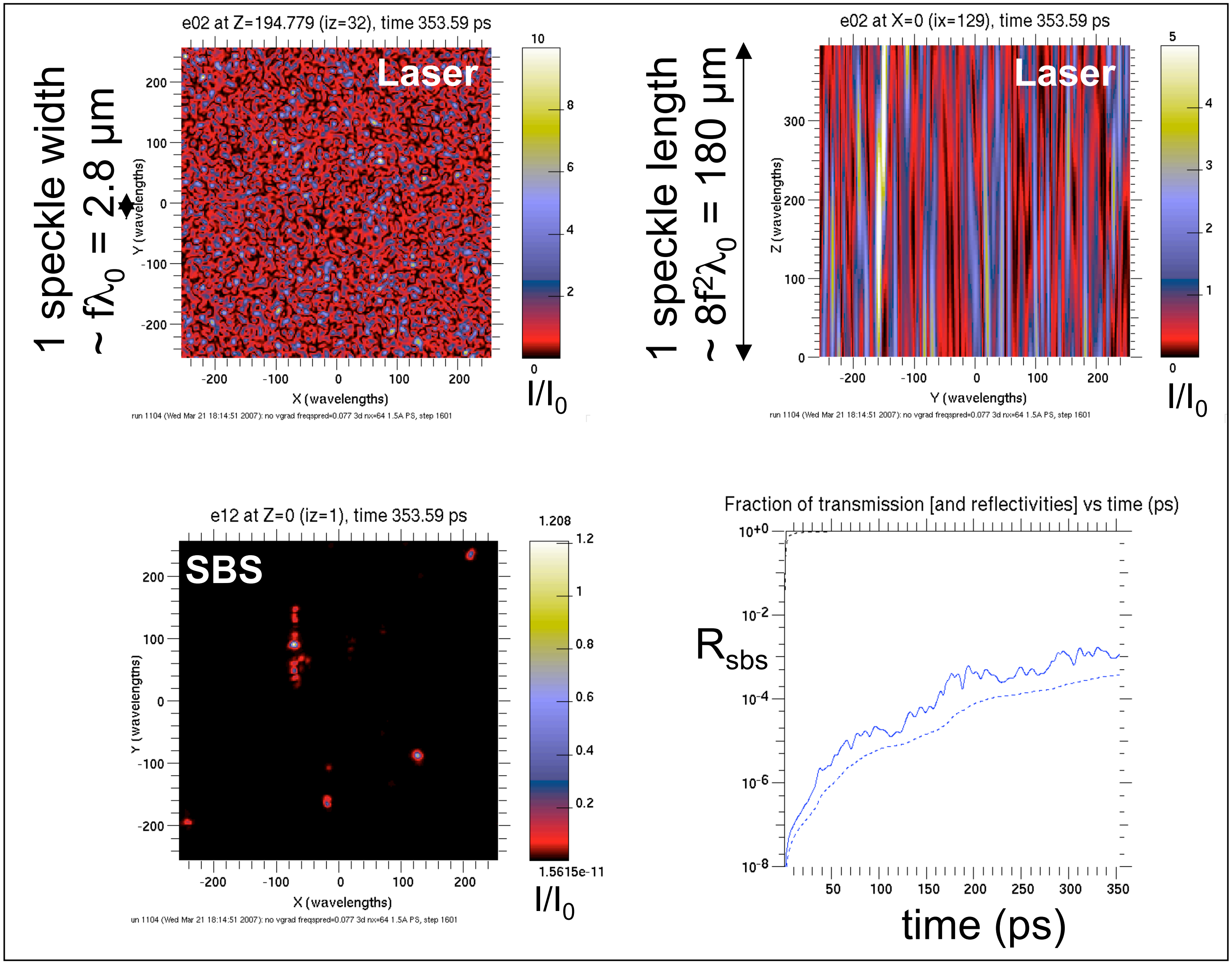


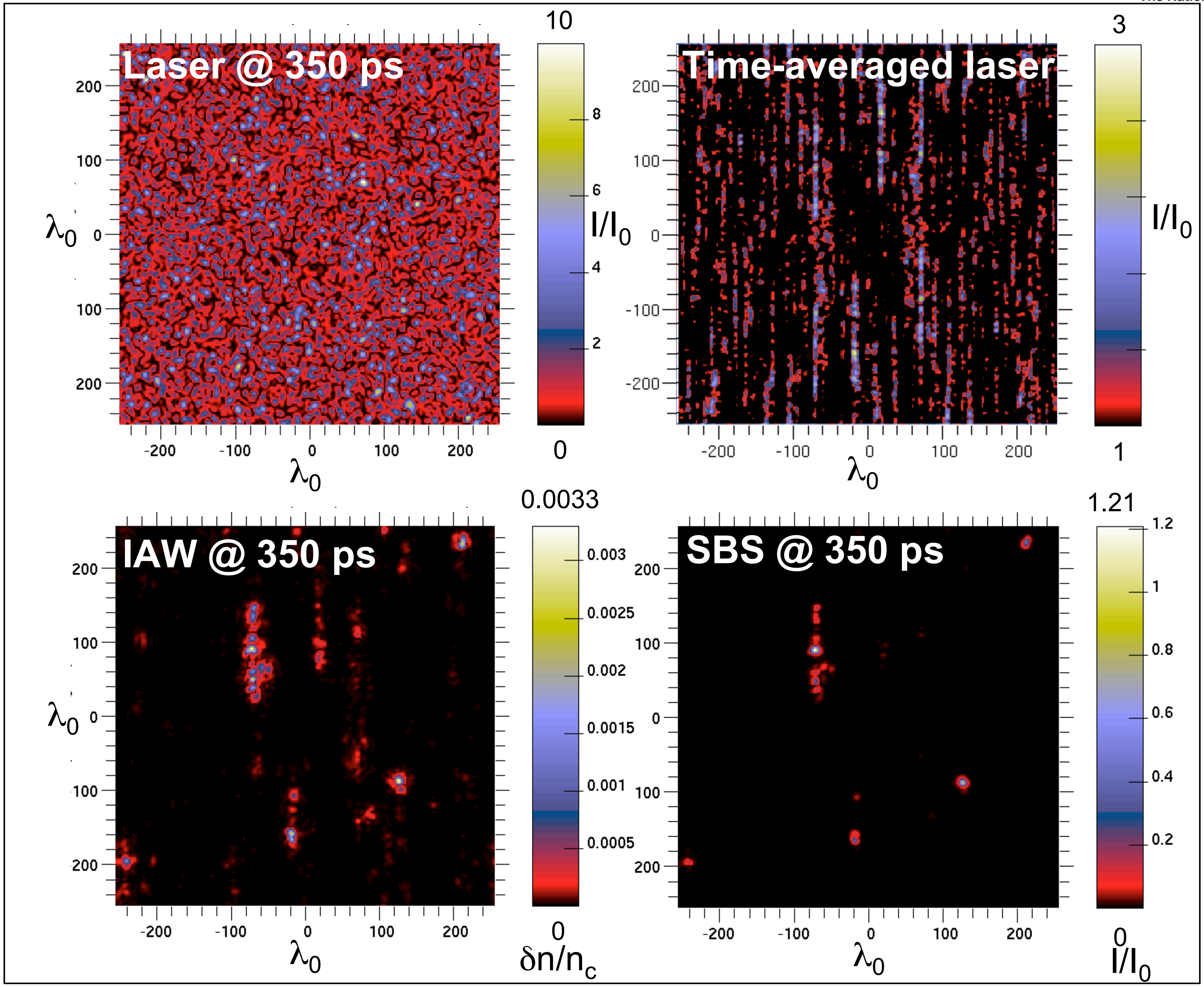
FIG. 3-39. (Color) SBS and SRS from Nova scale-1 hohlraums with NIF-like smoothing using 17 GHz SSD with a KPP. The reflectivities are similar to those from earlier Nova scale-1 hohlraum experiments using 3 GHz SSD and an RPP. Polarization smoothing does not have a significant effect for these plasma and laser conditions [S. H. Glenzer *et al.*, Phys. Plasmas **8**, 1692 (2001)].

pF3d simulations of a 1-speckle-long Au plasma (here 1.5 Å SSD @ 10 Ghz)



L = 180 µm
Te=3 keV
Ti=2 keV
Z=60
N_e/N_c=0.2
I=10^{14}W.cm^{-2}

The SBS driven IAW and backscattered light is correlated to the time-averaged laser intensity pattern



SSD model and power distribution

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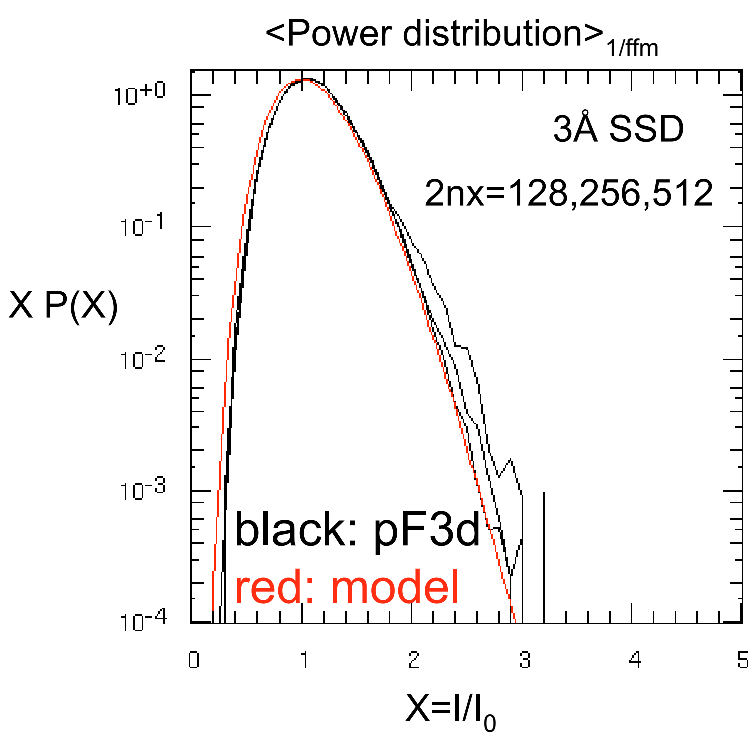
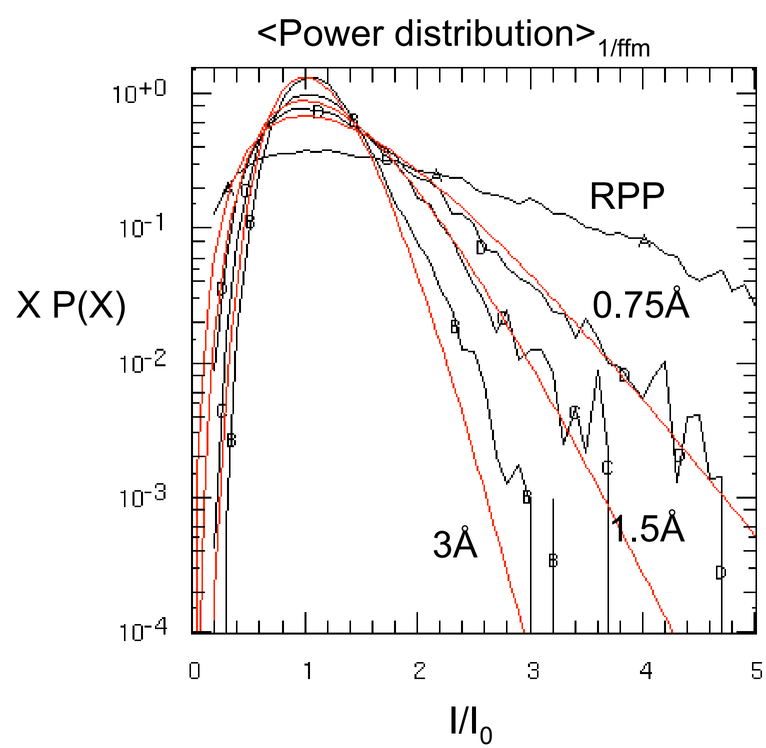
- SSD parameters: ffm = 17 Ghz modulator and $\Delta\lambda$ Å of bandwidth at 1ω
- Correlation time: t_c(ps) = 12.34/$\Delta\lambda$(Å); depth of modulation: $n_f = (ffm^*t_c)^{-1}$
- **1D model : change laser intensity every t_c with p.d. $p(I_n)=\exp(-I_n/I_0)$**

$$P(<I>_{1/ffm}=x) = n_f e^{-n_f x}\frac{(n_f x)^{n_f-1}}{(n_f-1)!}$$





Best match is when we use t_c(model) = 0.83 t_c

Most simple SBS model with time dependence

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$$V\partial_x a_1 - \gamma_0 a_2 = 0; (\partial_t + \nu)a_2 - \gamma_0 a_1 = S$$

$$\gamma_0^2 = \frac{1}{16}\frac{v_{osc}^2}{v_e^2}\frac{n_e}{n_c}\frac{\omega_a\omega_0}{1+k_a^2\lambda_{De}^2}$$

$$\partial_x G_1 - G^{1/2}G_2 = 0; (\partial_t + 1)G_2 - G^{1/2}G_1 = \delta(x)\delta(t);$$

$$G_2(x,t) = H(t)e^{-t}\delta(x) + H(x)e^{-t}\sqrt{Gt/x}I_1(2\sqrt{Gxt})$$

$$G_1(x,t) = H(x)e^{-t}\sqrt{G}I_0(2\sqrt{Gxt})$$

Note that the only parameter if G (the 1-D gain)

The formal solution to (1) is then $a_2(n\tau_c) = \sum_{i=1}^{n}\prod_{k=n}^{i} G_k * S$ where

$$\prod_{k=n}^{i} G_k * S \equiv \int_0^1 .. \int_0^1 G_n(1-x_n)G_{n-1}(x_n - x_{n-1}).. \int_0^{\tau_c} G_i(x_{i+1}-x_i,t)dtdx_i..dx_n$$

and $G_n(x) = G_2(x, t = \tau_c, I = I_n)$.

and after some algebra

$$\max_n[< R_n >= e^{G_0\tau_c/2}e^{\sqrt{(4n+3)G_0\tau_c}}e^{-n\tau_c}] \propto e^{G_0(1+\tau_c/2)}$$

The model predicts a strong effect of SSD on SBS for (intensity) gain $2g_0 < 20$

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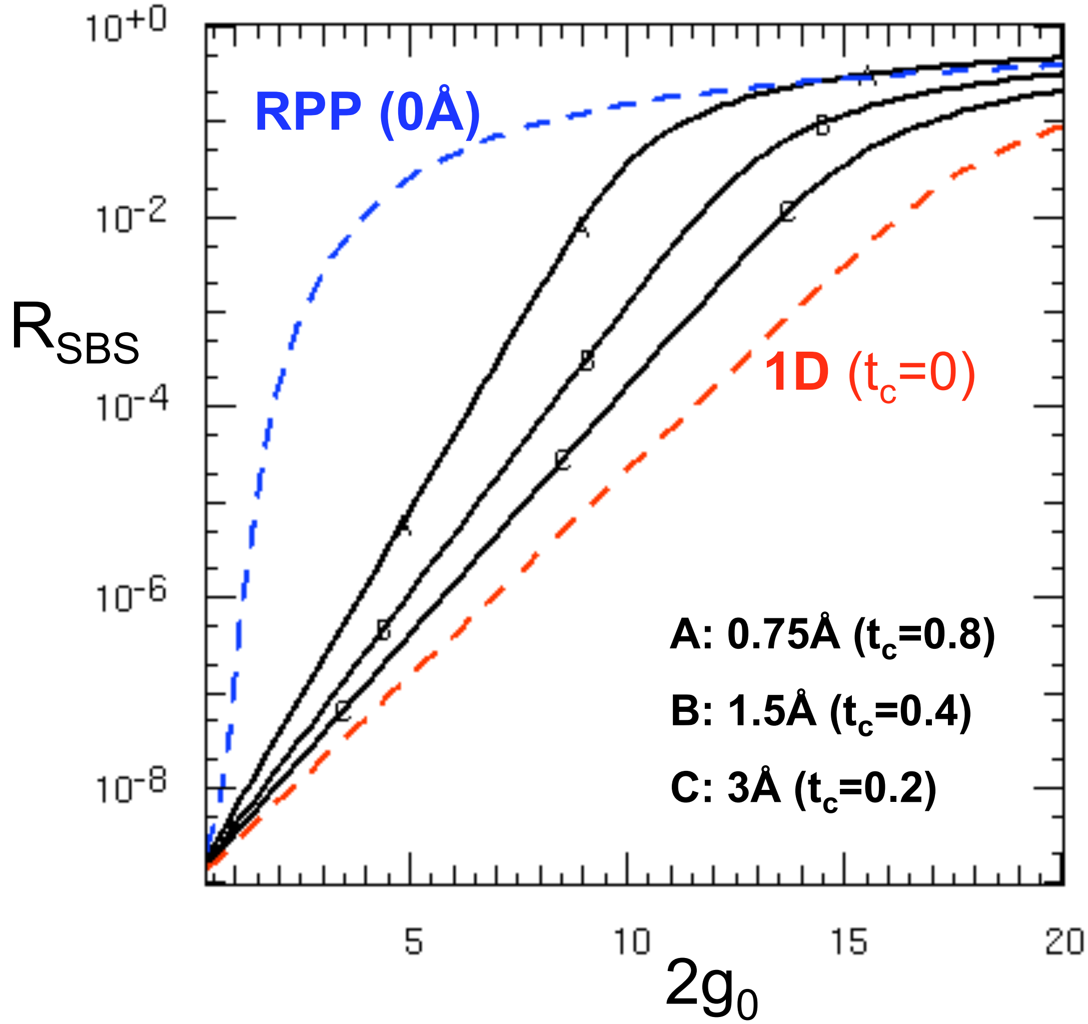
Tang-like pump depletion model
$R(1-R) = \varepsilon \exp[2g_0(1+t_c)(1-R)]$ $\varepsilon=10^{-9}$ (Thomson scattering) g_0 = linear convective gain $t_c \equiv \nu(\text{IAW}) \times t_c(\text{SSD})$ $\sim 0.07(\text{ps}^{-1}) \times (10/\Delta\lambda(\text{Å}))$

Te=3 keV
Ti=2 keV
Z=60
$N_e/N_c=0.2$

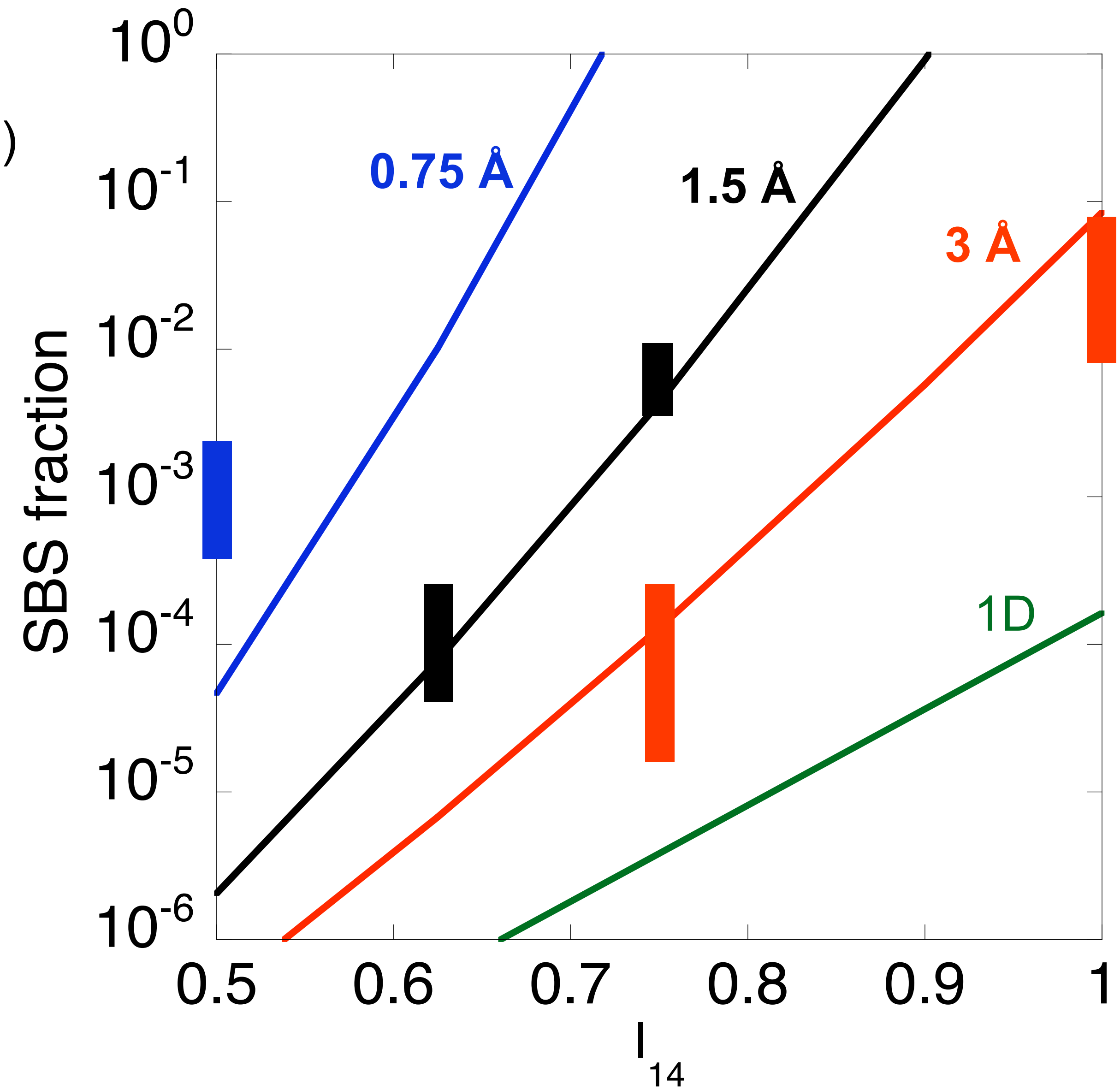


Our model reproduces the trend of full 3D pF3d simulations

pF3d, nx=ny=256
NIF SSD (ffm=17 Ghz)

model

L = 180 µm
Te = 3 keV
Ti = 2 keV
Z = 60
Ne/Nc = 0.2
I = 0.5-1x10^{14}W.cm^{-2}
$2g_0 = 14\ I_{14}$
abs. threshold:
I_{14}>2.7



Polarization smoothing double the effective bandwidth

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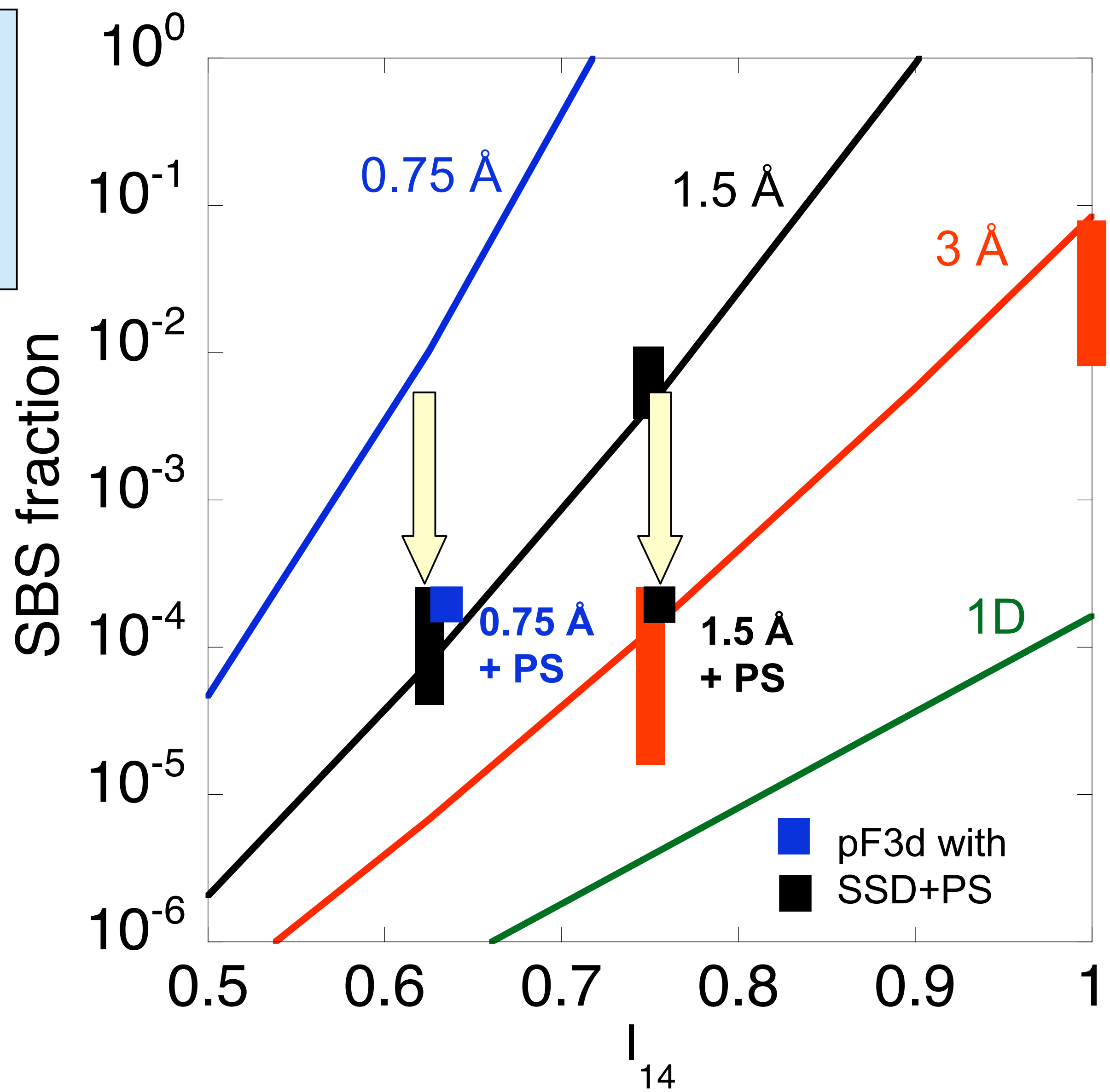
Replace $P_{RPP}(I) = \exp(-I)$,
which gave $R \sim \exp[2g_0(1+t_c)]$,
with $P_{PS}(I) = 4I \exp(-2I)$ to get
$R \sim \exp[2g_0(1+t_c/2)]$



In this regime, the maximum effect of SSD depends on the depth of modulation (for a given bandwidth)

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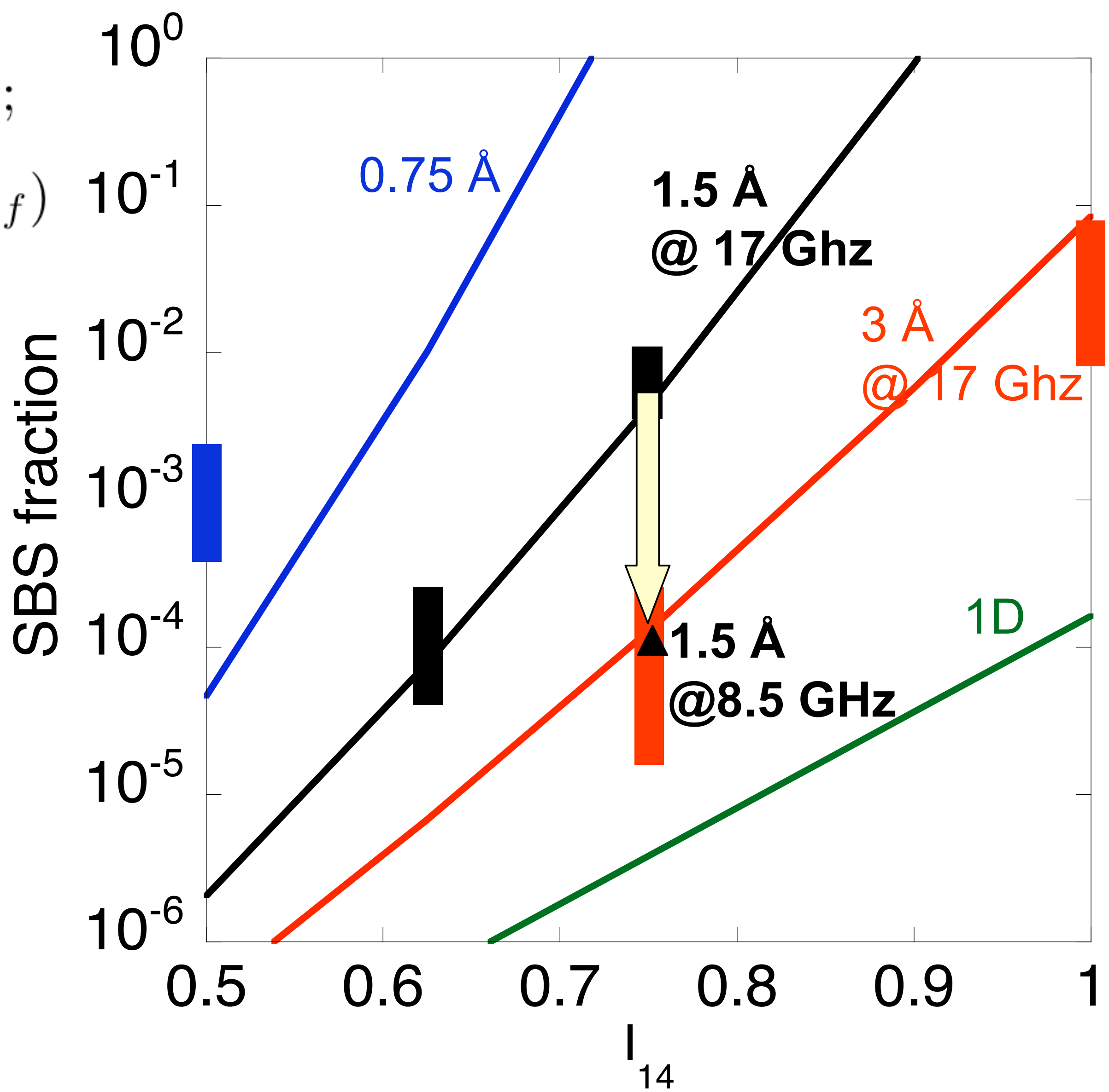
$$R \propto \exp[2g_0(1+g_0/N)];$$

$$N = \min(n_{sat} \equiv g_0/\tau_c, n_f)$$

1.5Å @ 17 Ghz; I_{14} = 0.75
g_0=5.25; t_c = 0.4
n_{sat} = 13 > $\mathbf{n_f = 9}$
N = 9
R ~ exp[10.5 x (1+0.6)]~e^{17}

1.5Å @ 8.5 Ghz; I_{14} = 0.75
g_0=5.25; t_c = 0.4
n_{sat} = 13 < $\mathbf{n_f = 18}$
N = 13
R ~ exp[10.5 x (1+0.4)]~e^{15}



Conclusion

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- We have developed a 1D model to quantify the mitigation of SBS with SSD and PS in a high-Z short plasma (i.e. hohlraum wall) and validated vs. 3D pF3d simulations[1]

- The effective 1D gain is:

  - $2g_0(1+t_c)$ for the intensity (ISI-like smoothing)
  - $2g_0(1+g_0/N)]; \; N = \min(n_{sat} \equiv g_0/\tau_c, n_f)$ for SSD
  - $2g_0(1+t_c/2)$ with polarization smoothing (ISI + PS)

- This model and 3D pF3d simulations predict that SSD should strongly reduce SBS from a high Z speckle-long plasma if the linear gain remains below 20

- On NIF, the additional 3 Ghz modulator should break the cyclic redundancy of the 17 Ghz modulator -> “ISI”-like SSD

[1] “Controlling Stimulated Brillouin backscatter with beam smoothing in weakly damped systems”, L. Divol, accepted for publication in Phys. Rev. Lett. (September 2007)