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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

**Presentation to
Anomalous Absorption 2007**



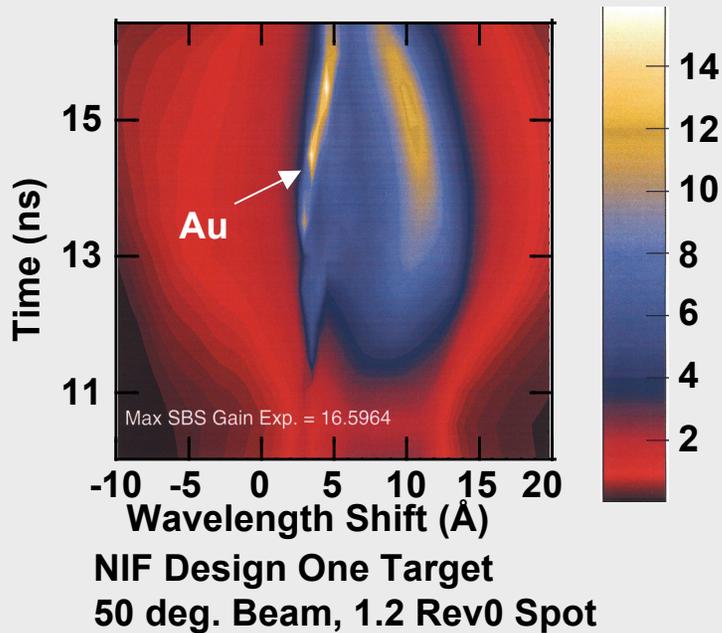
L. Divol

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

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



Typical NIF Outer Beam Plasma Parameters

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

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

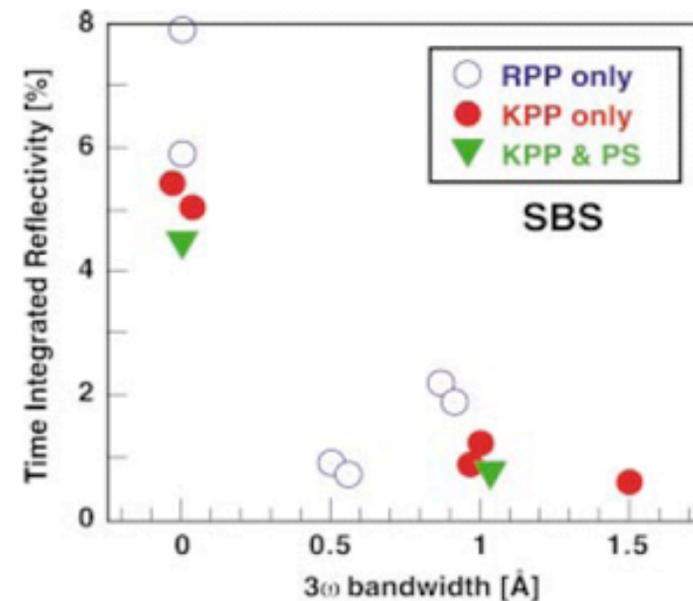


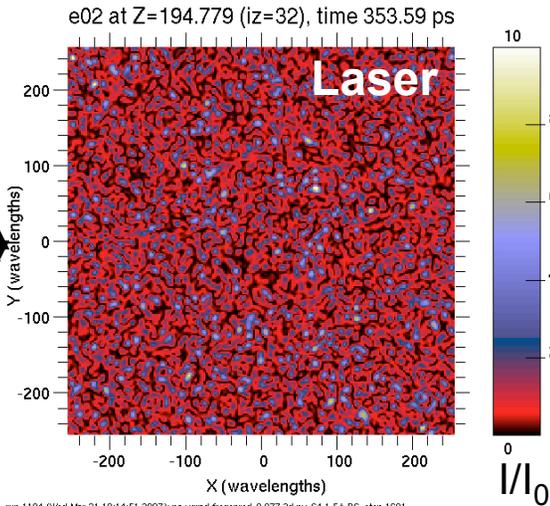
FIG. 3-39. (Color) SBS and SRS from Nova scale-1 hohlraums with NIF-like smoothing using 17 GHz SSD with a KPP. The reflectivities are similar to those from earlier Nova scale-1 hohlraum experiments using 3 GHz SSD and an RPP. Polarization smoothing does not have a significant effect for these plasma 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)



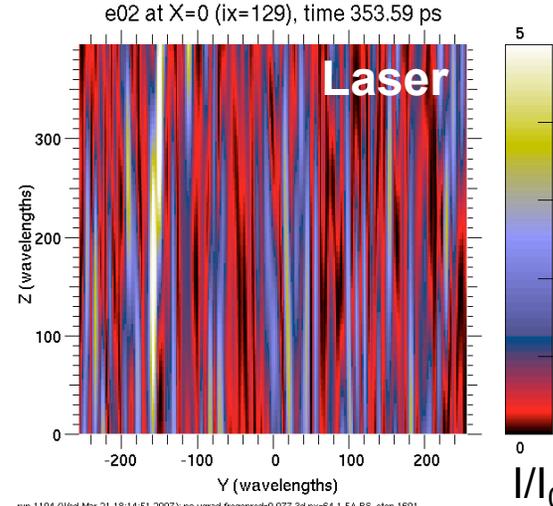
The National Ignition Campaign

1 speckle width
 $\sim f\lambda_0 = 2.8 \mu\text{m}$



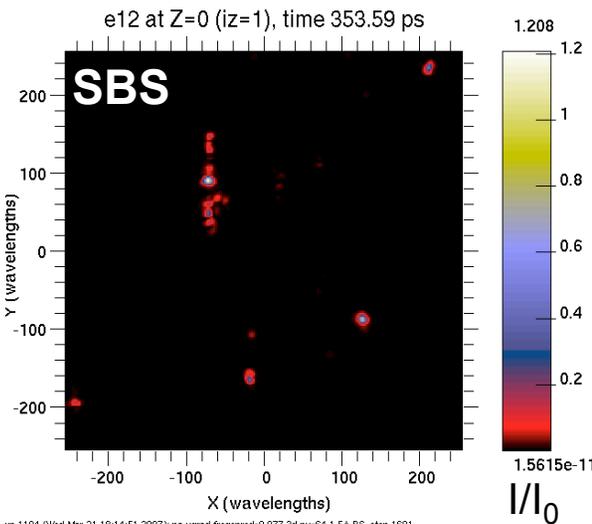
run 1104 (Wed Mar 21 18:14:51 2007); no vgrad freqspred=0.077 3d nix=64 1.5A PS, step 1601

1 speckle length
 $\sim 8f^2\lambda_0 = 180 \mu\text{m}$

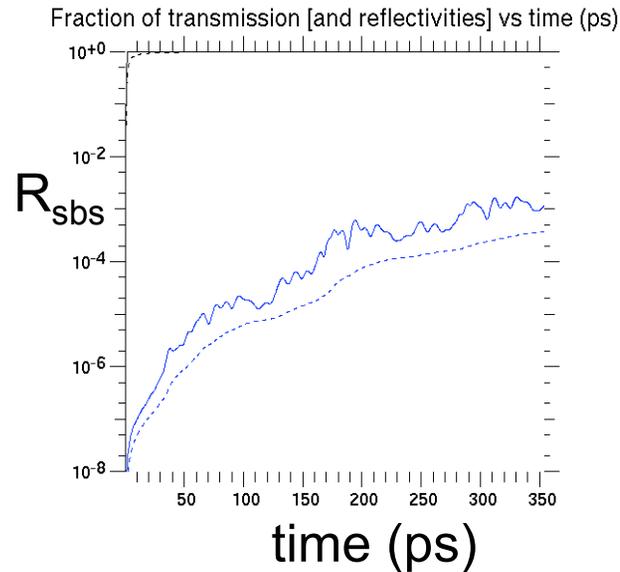


run 1104 (Wed Mar 21 18:14:51 2007); no vgrad freqspred=0.077 3d nix=64 1.5A PS, step 1601

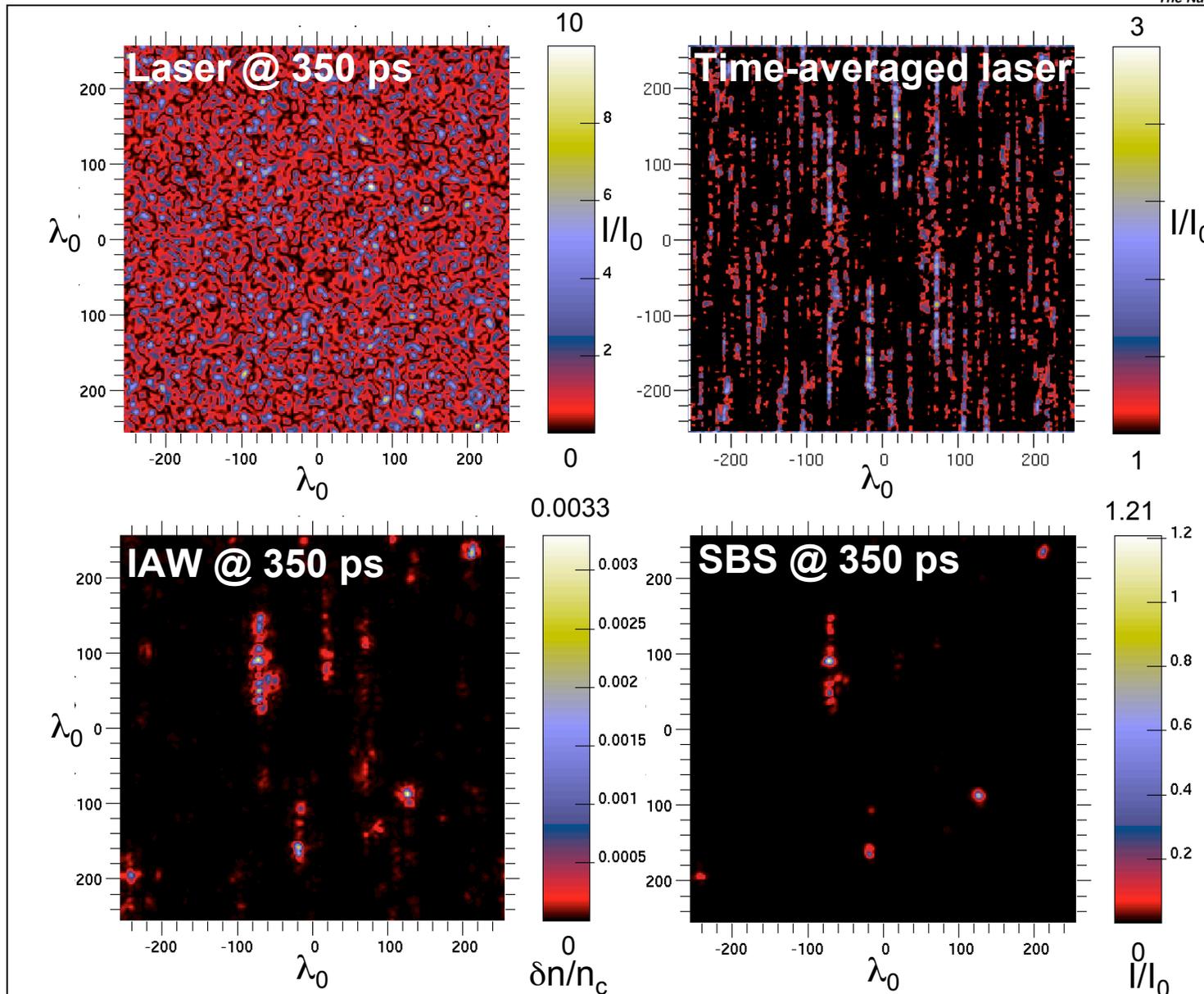
$L = 180 \mu\text{m}$
 $T_e = 3 \text{ keV}$
 $T_i = 2 \text{ keV}$
 $Z = 60$
 $N_e/N_c = 0.2$
 $I = 10^{14} \text{ W.cm}^{-2}$



un 1104 (Wed Mar 21 18:14:51 2007); no vgrad freqspred=0.077 3d nix=64 1.5A PS, step 1601



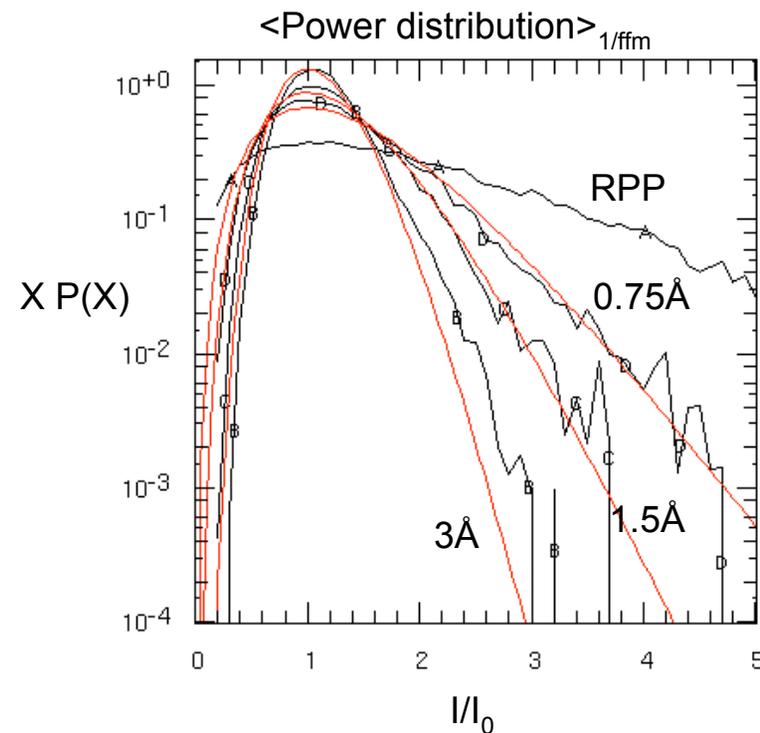
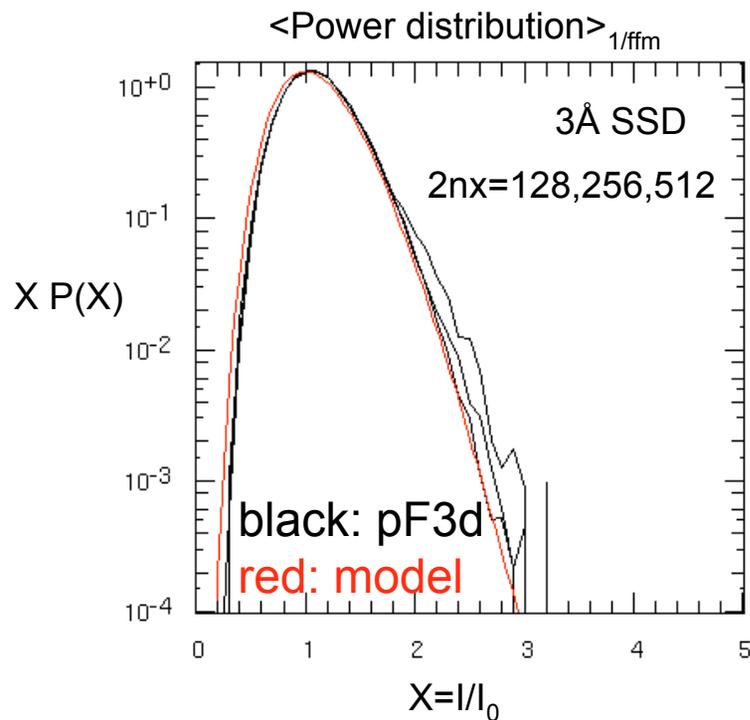
The SBS driven IAW and backscattered light is correlated to the time-averaged laser intensity pattern



SSD model and power distribution

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

$$P(\langle I \rangle_{1/ffm} = x) = n_f e^{-n_f x} \frac{(n_f x)^{n_f - 1}}{(n_f - 1)!}$$



Best match is when we use $t_c(\text{model}) = 0.83 t_c$

Most simple SBS model with time dependence

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

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

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

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

$$G_1(x, t) = H(x)e^{-t}\sqrt{GI_0(2\sqrt{Gxt})}$$

Note that the only parameter is 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

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

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

and after some algebra

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

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

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

$t_c \equiv \nu(\text{IAW}) \times t_c(\text{SSD})$

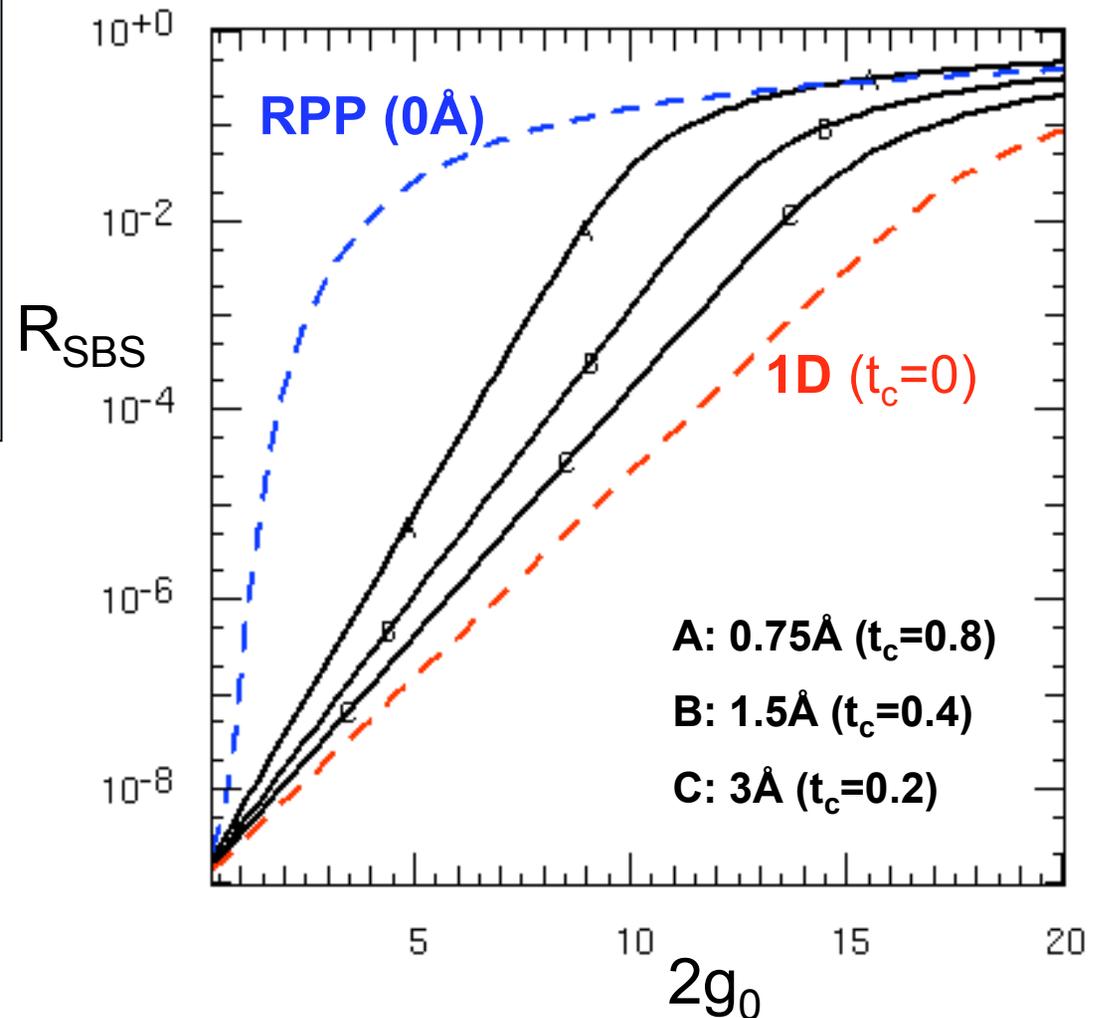
$\sim 0.07(\text{ps}^{-1}) \times (10/\Delta\lambda(\text{\AA}))$

$T_e = 3 \text{ keV}$

$T_i = 2 \text{ keV}$

$Z = 60$

$N_e/N_c = 0.2$

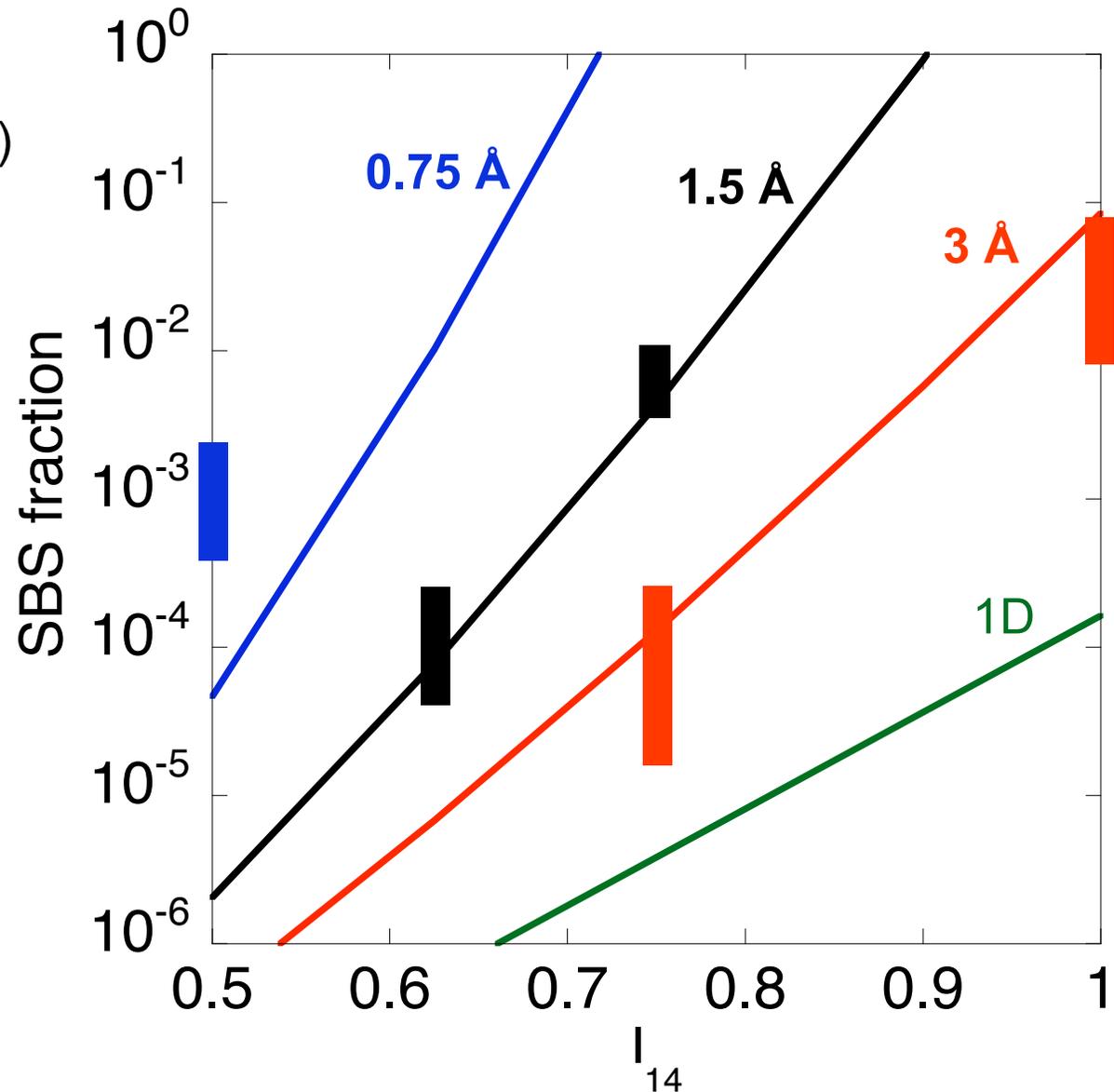


Our model reproduces the trend of full 3D pF3d simulations

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

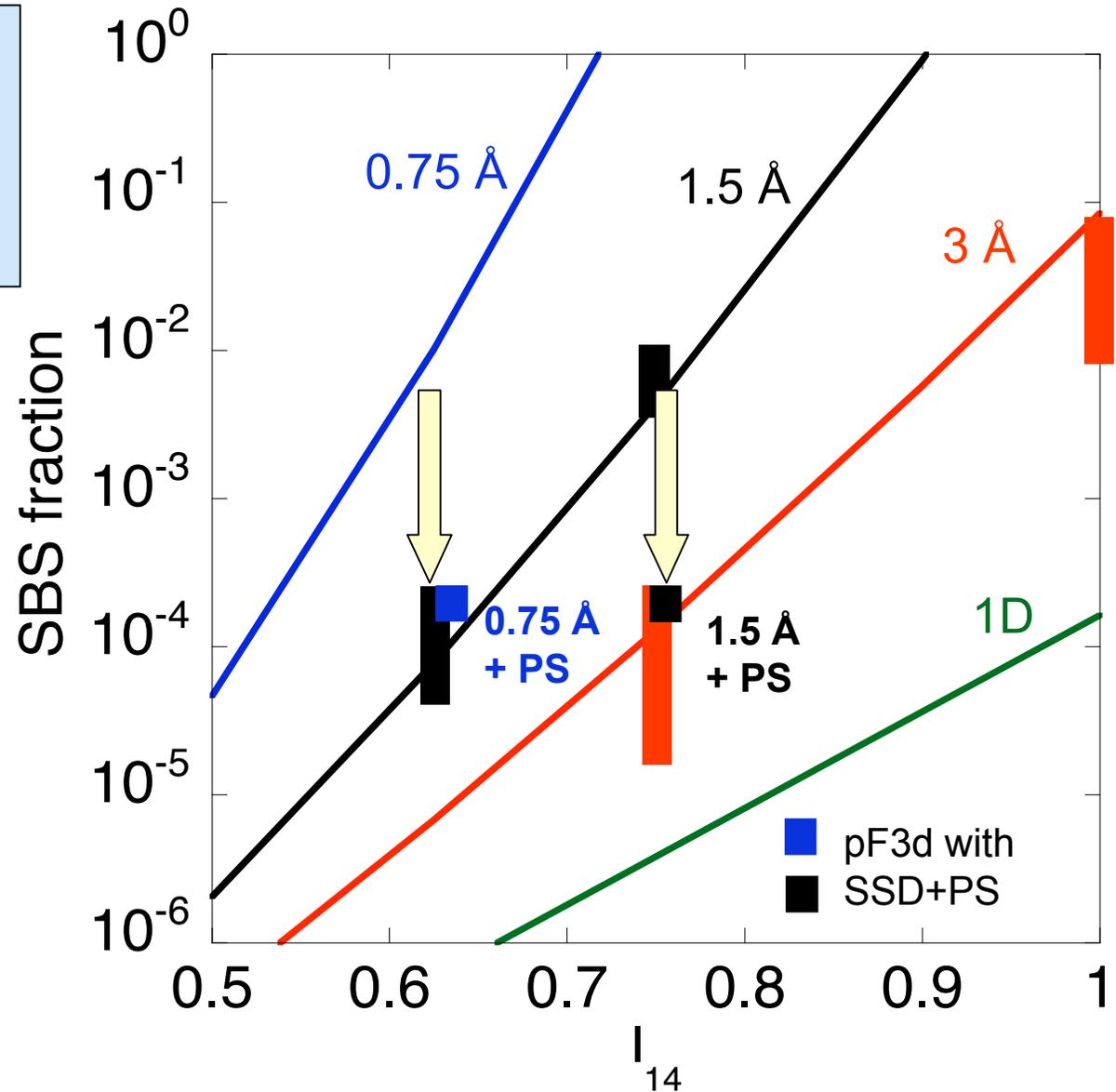
| model

L = 180 μm
Te = 3 keV
Ti = 2 keV
Z = 60
Ne/Nc = 0.2
I = 0.5-1x10¹⁴W.cm⁻²
2g₀ = 14 I₁₄
abs. threshold:
I₁₄>2.7



Polarization smoothing double the effective bandwidth

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)

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

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

1.5Å @ 17 GHz; $I_{14} = 0.75$

$g_0 = 5.25$; $\tau_c = 0.4$

$n_{sat} = 13 > n_f = 9$

N = 9

$R \sim \exp[10.5 \times (1+0.6)] \sim e^{17}$

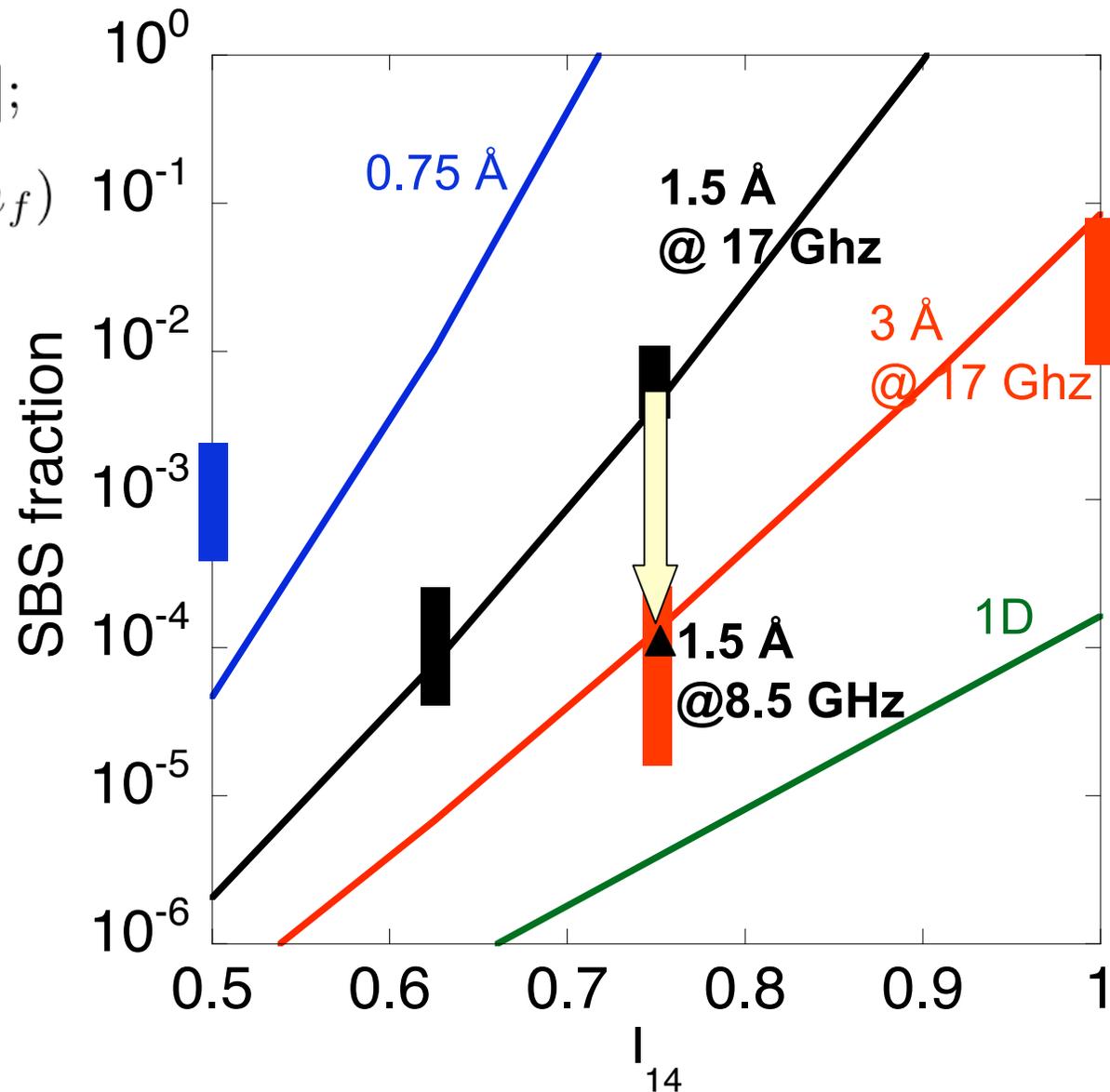
1.5Å @ 8.5 GHz; $I_{14} = 0.75$

$g_0 = 5.25$; $\tau_c = 0.4$

$n_{sat} = 13 < n_f = 18$

N = 13

$R \sim \exp[10.5 \times (1+0.4)] \sim e^{15}$



Conclusion

- 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)