Numerical Two-Dimensional Studies of Near-Forward Stimulated Brillouin Scattering of Laser Beams in Plasmas

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In previous papers[1,2] we analytically studied the one-dimensional spatiotemporal evolution of near-forward stimulated Brillouin scattering (FSBS) in different regimes. As an expansion of this analysis we developed a numerical code that solves the light-propagation equation in the paraxial wave approximation coupled with the ion-acoustic wave equation in two-dimensional Cartesian geometry. Solution assumes nonperiodic boundary conditions in the direction of propagation of the light beam. This model allows the investigation of three- and four-wave coupling in the context of FSBS along with filamentation and focusing instabilities. These code properties give rise to the numerical simulations studying how the smoothing of the laser beam affects its propagation in the plasmas. This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC03- 92SF19460, the University of Rochester, and the New York State Energy Research and Development Authority.

1. C. J. McKinstrie, J. S. Li, and A. V. Kanaev, Phys. Plasmas **4**, 4227 (1997).
2. A. V. Kanaev and C. J. McKinstrie, Phys. Plasmas **5**, 4511 (1998).

Numerical Two-Dimensional Studies of Near-Forward Stimulated Brillouin Scattering and Filamentation Instability in Plasmas

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Introduction

- At small scattering angles, FSBS becomes a four-wave process and merges with filamentation; it is relevant to the pump-probe energy transfer experiments and studies of the SSD smoothing technique on OMEGA.
- Transient forward SBS and filamentation were observed in recent experiments with two crossed laser beams.[1,2]
- Phase plates combined with bandwidth seed forward SBS as well as filamentation and result in enhancement of intensity variations.[3]
- Spatiotemporal transients dominate the four-wave interaction and that precludes a steady-state analysis.
- Numerical 2-D model is developed for the spatiotemporal analysis of the transient FSBS and filamentation instability.

1. A. K. Lal *et al.*, Phys. Rev. Lett. 78, 670 (1997).
2. K. Marsh, C. Joshi, C. J. McKinstrie, and J. S. Li, submitted to Phys. Plasmas.
3. R. W. Short, 29th Annual Anomalous Absorption Conference, Monterey, CA, 1999.

A numerical two-dimensional model for forward SBS and filamentation is developed

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- Code solves the system of coupled equations: light-wave equation in the paraxial approximation

$$\left(\frac{c_s}{c}\partial_t + \partial_z - \frac{i}{2}\partial_{xx}\right) = -\frac{i\,\omega_e^2}{2\,\omega_0^2}\,An,$$

where c and c_s are light and sound speeds, respectively; ω_0 is a pump light frequency; A is a vector potential; $n = \Delta N/N$ is normalized ion plasma density; and ion-acoustic equation

$$\left(\partial_{tt} + 2\nu\partial_t - \partial_{xx} - \partial_{zz}\right)n = \frac{1}{2}\left(\partial_{xx} + \partial_{tt}\right)|A|^2,$$

where ν models the damping of the sound wave.

- Periodical boundary conditions are imposed on both waves in the transverse direction (x axis).
- Transparent boundary conditions in the direction of the propagation of the light wave (z axis) allow ion-acoustic wave to propagate freely out of the experiment box.
- Split-step method used to resolve the propagation of the light wave allows for arbitrary initial profile of the laser beam.

Previously 1-D linear model for FSBS and filamentation was studied analytically and numerically

- **Linearized 1-D forward four-wave mixing (FFWM) equations are**

$$\left(\partial_z \pm iK\right)A_{\pm} = \mp i\gamma A_0 n$$

$$\left(\partial_{tt}^2 + 2\nu\,\partial_t + \omega_s^2\right)n = -2i\,\omega_s\gamma\left(A_0^* A_+ + A_0 A_-\right),$$

where A_0 denotes a pump light wave, A_+ and A_- are anti-Stokes and Stokes light waves, respectively.

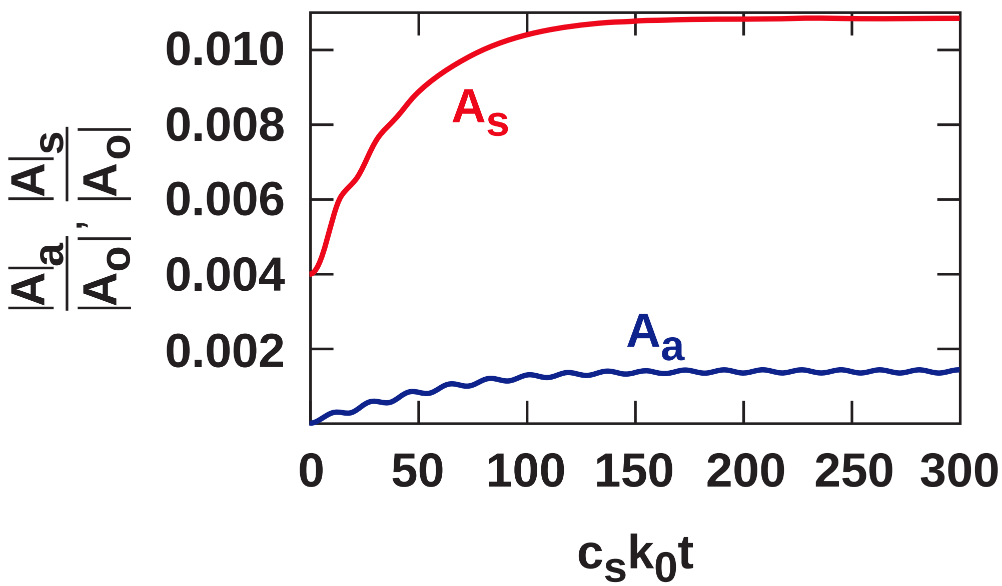
- **Asymptotic analysis shows that in the weak-coupling regime (which corresponds to most experimental conditions) parameter $\alpha = K\nu/(\gamma A_0)^2$ determines if interaction includes three or four waves.**

For $\alpha >> 1$, FSBS is a three-wave process

- The anti-Stokes response can be neglected *a priori*.
- Stokes impulse response grows asymptotically in time as

$$G_{-}(t, z) \sim \frac{i\gamma \exp\left[iKz + 2A_0\gamma(tz)^{1/2} - \nu t\right]}{2(A_0\gamma\pi)^{1/2}(tz)^{1/2}}$$

- For $n/n_{crit} = 0.1$, $\nu = 0.2\ \omega_s$, $A_0 = 0.25$, and 10° scattering angle ($\alpha = 3.85$), 2-D code shows that the growth of the seeded Stokes wave is larger than the growth of the anti-Stokes light wave.

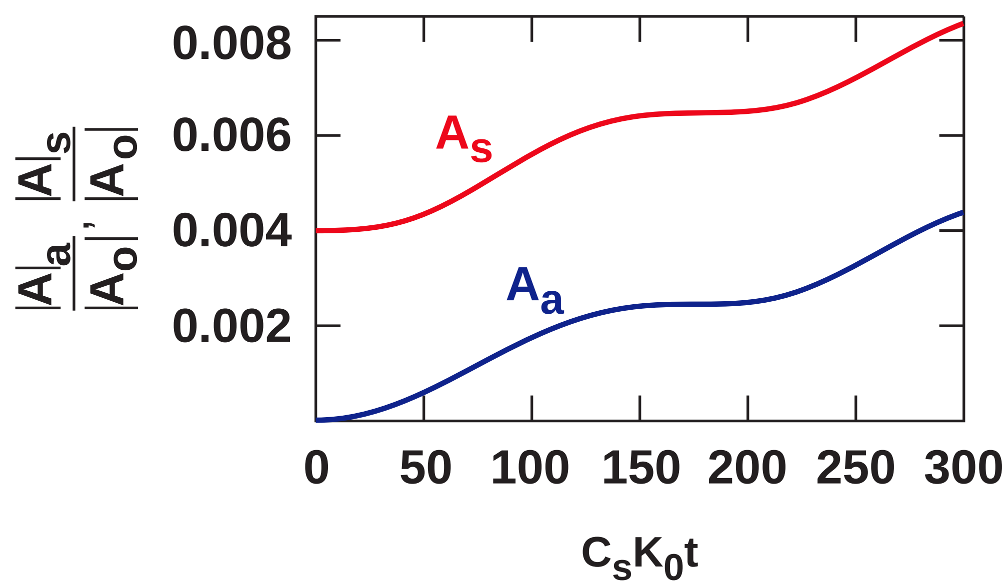


For α << 1, FSBS is a four-wave process

- The anti-Stokes and Stokes impulse responses are comparable according to asymptotic analysis.
- Stokes and anti-Stokes impulse responses grow in time as

$$G_{\pm}(t, z) \sim \mathrm{m} \frac{(\gamma A_0) e^{i5\pi/12} \exp\left\{3e^{i\pi/b}\left[(\gamma A_0)^2 k z^2 t/2\right]^{1/3} - \nu t\right\}}{(12\pi)^{1/2}\left[(\gamma A_0)^2 k z^2 t/2\right]^{1/6}}.$$

- For $n/n_{crit} = 0.1$, $\nu = 0.03\ \omega_s$, $A_0 = 0.25$, and 1° scattering angle (α . 0.001), the results of 2-D code show that the amplitudes of the Stokes and anti-Stokes waves are comparable.



Linear 1-D code and nonlinear 2-D code give comparable results for the initial evolution of the FSBS

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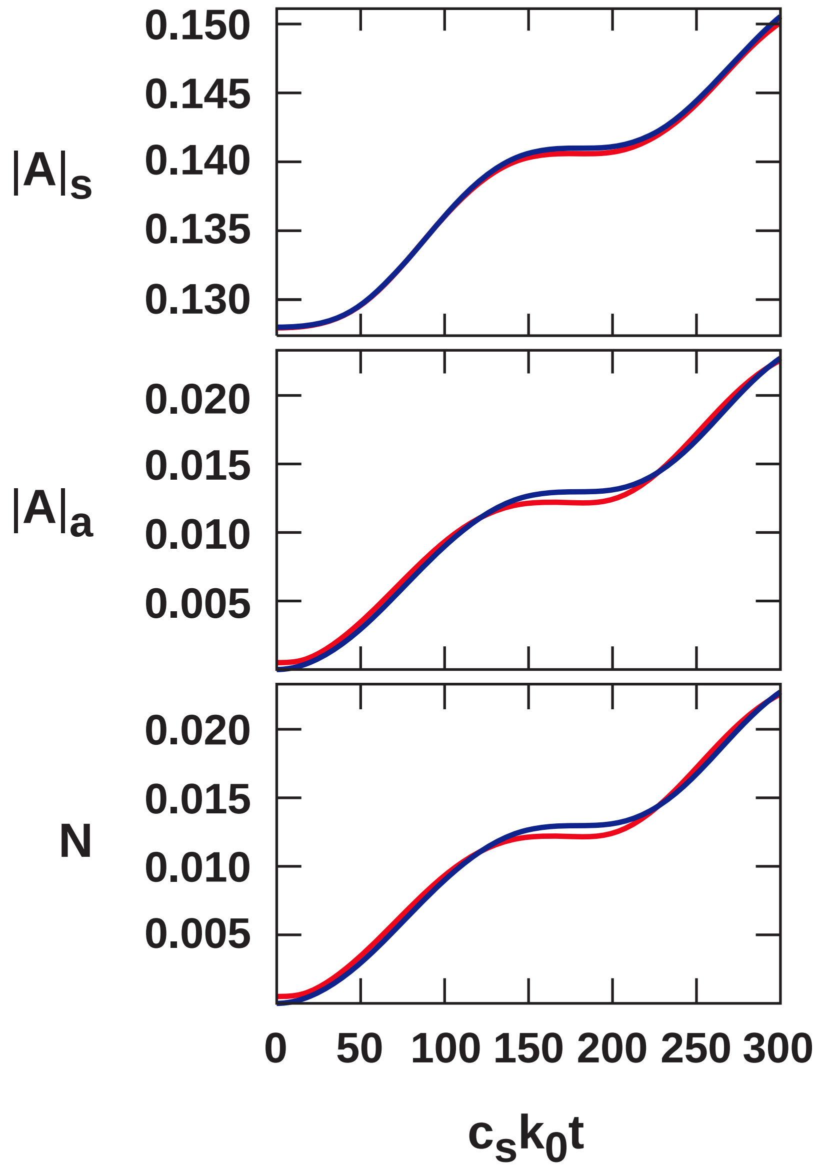
- The uniform profile pump beam and periodical profile probe beam enter the box with plasma at rest.
- Time dependences of the Stokes, anti-Stokes, and ion-acoustic waves produced by 1-D and 2-D codes for a 1° scattering angle are in good agreement.



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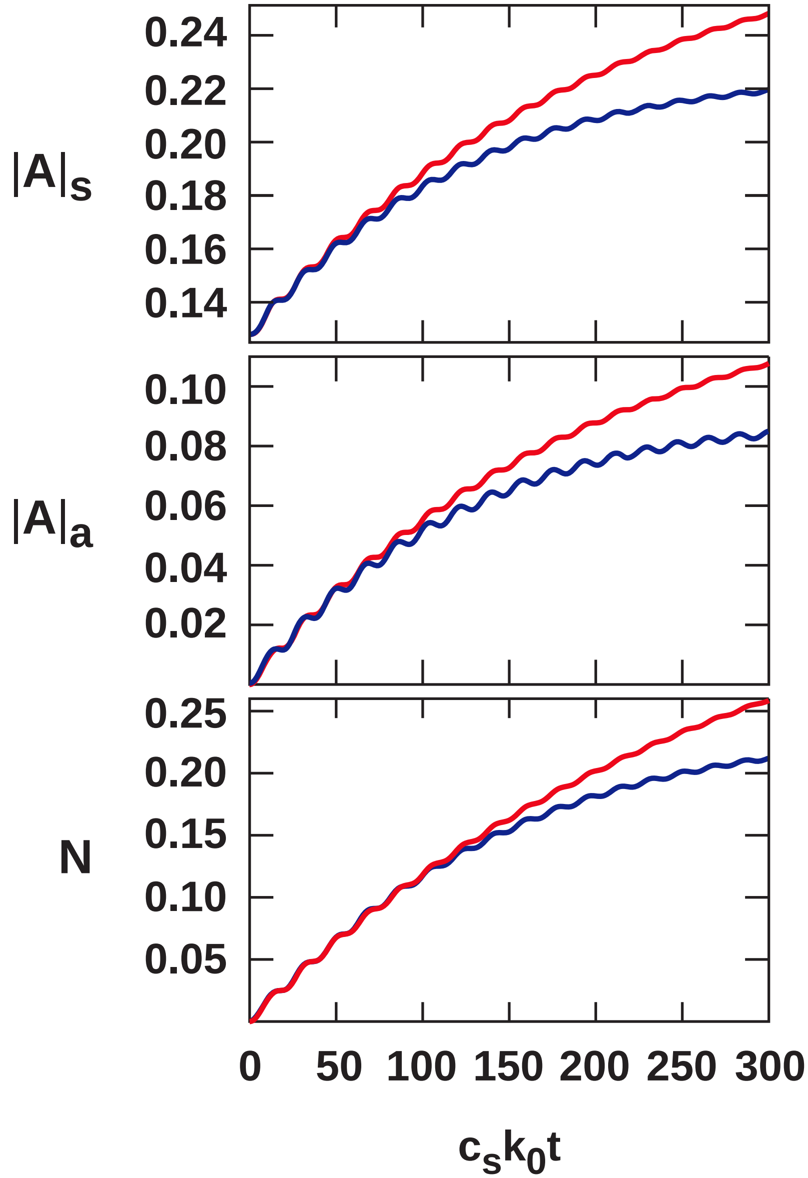
Linear 1-D code and nonlinear 2-D code give comparable results for the initial evolution of the FSBS (cont'd)

- The results of the 1-D and 2-D code simulations show that the time dependences of the Stokes, anti-Stokes, and ion-acoustic waves for 10° scattering angle are in good agreement for the first several sound-wave periods.

- The difference in the results at later time is mainly due to the plasma-wave propagation out of the experimental box in the z-axis direction in the 2-D code, whereas in 1-D code space dependence of the ion-acoustic wave is not resolved.



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The amplitude of the filamentation instability transients heavily depends on the rising time of the probe beam

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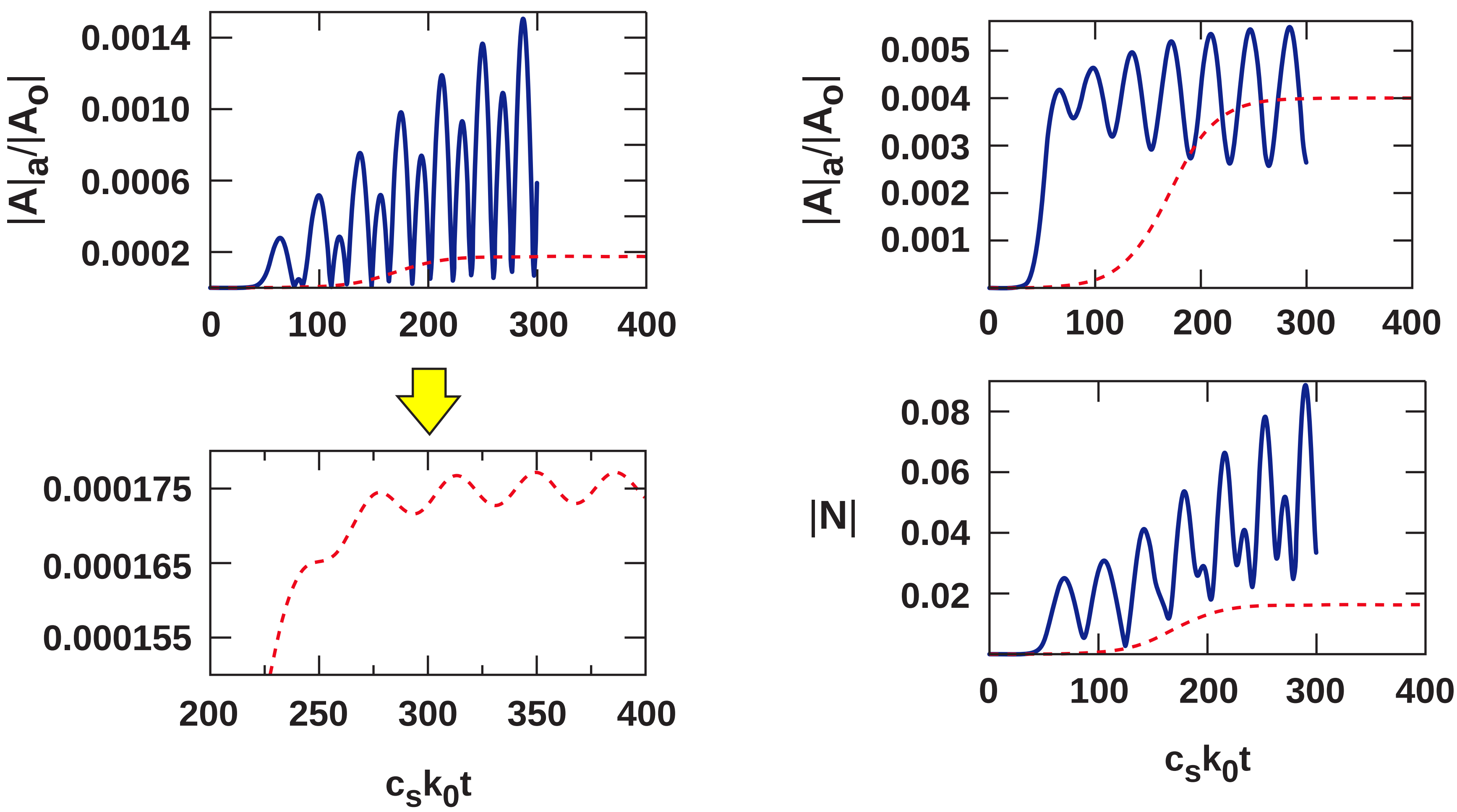

Rise time approximately 1.5 ω_s^{-1}

Rise time approximately 10 ω_s^{-1}

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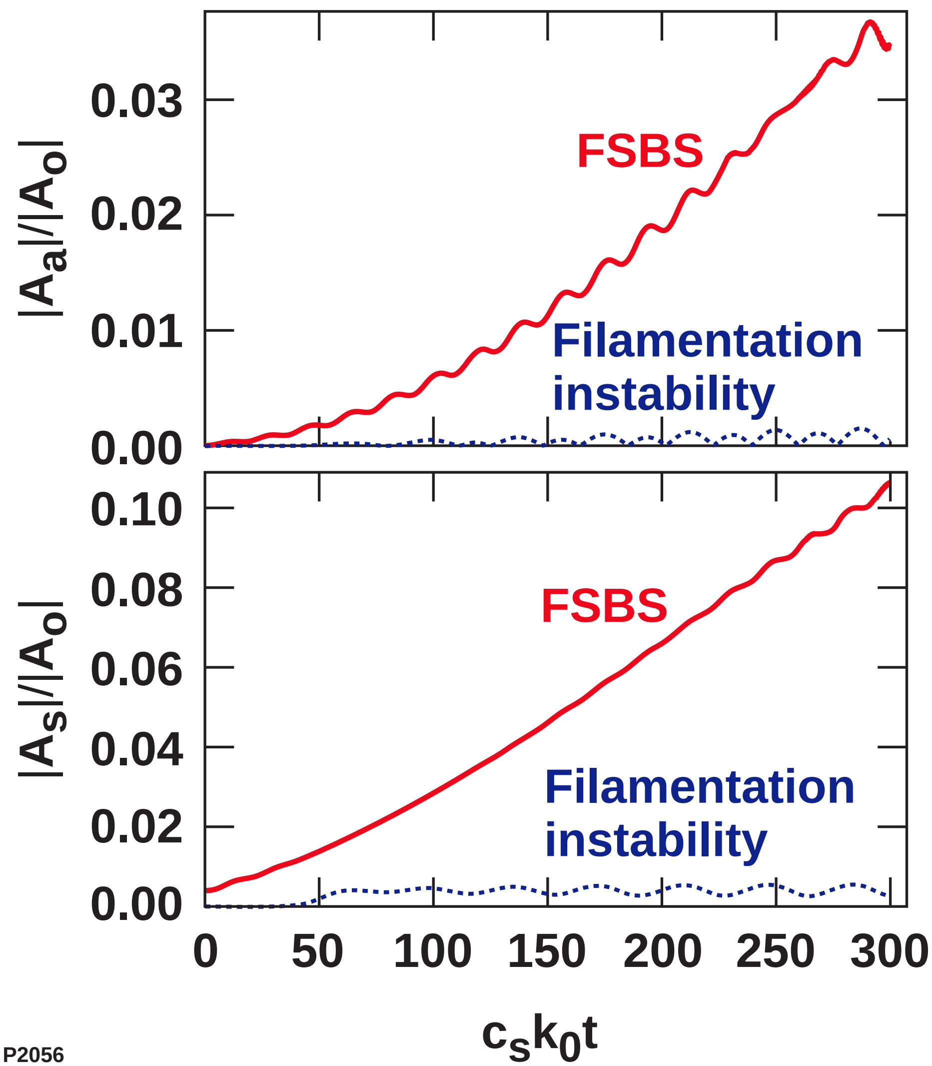
Typically, FSBS has larger growth rates than filamentation instability



- Comparison of the FSBS and filamentation instability for the scattering angle of 10°.

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Summary

- Interaction between crossed pump and probe beams models the energy transfer between speckles in the laser beam with bandwidths.
- The results of the 2-D nonlinear simulations show that asymptotic analysis of the 1-D linear model correctly predicts the range of parameters for the three- and four-wave regimes of the FSBS.
- Typically, FSBS has larger growth rates than filamentation instability.
- Spatiotemporal transients dominate the four-wave interaction; their amplitudes, in the case of filamentation, heavily depend on the rising time of the probe laser beam.