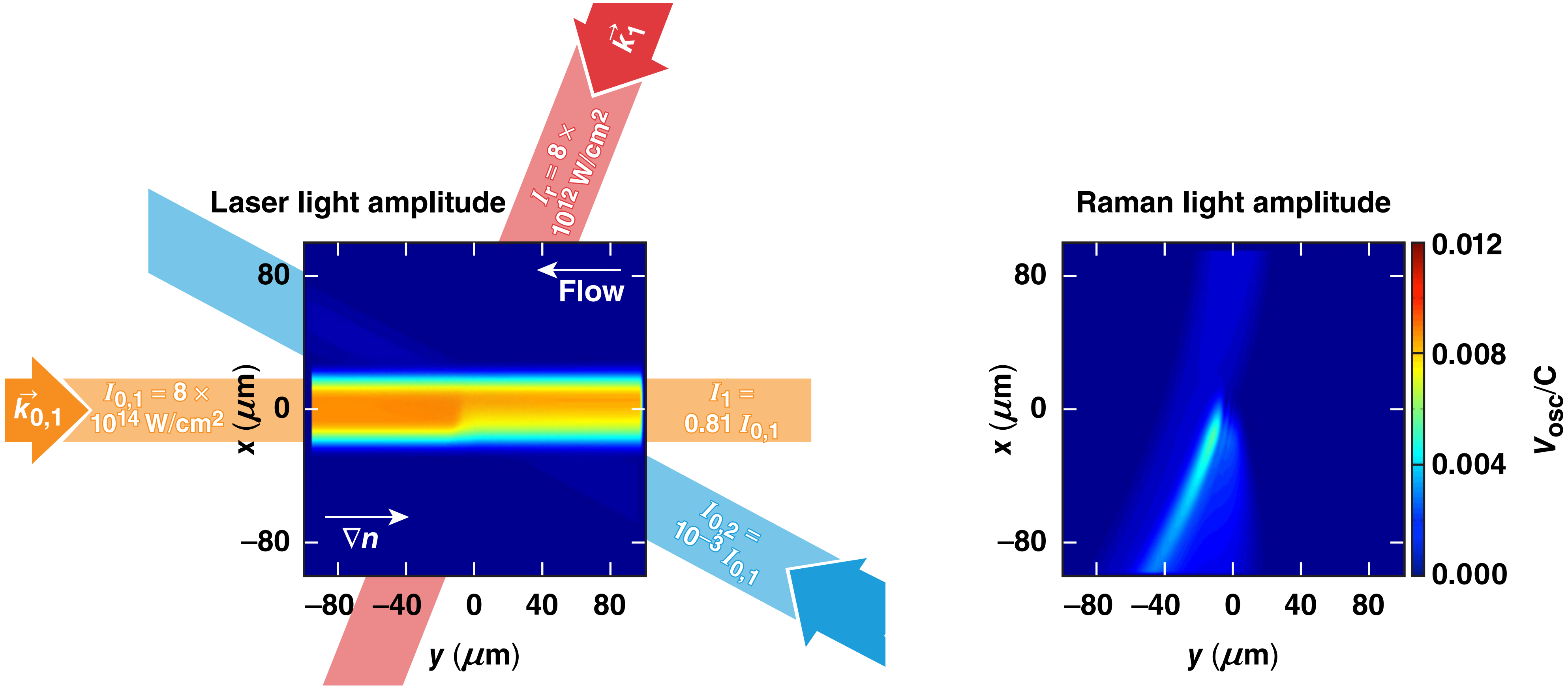
Modeling of Stimulated Raman Scattering in Direct-Drive Inertial Confinement Fusion Plasmas for National Ignition Facility Conditions



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23–27 October 2017

Summary

A new wave-based model has been used to examine the interplay between stimulated Raman scattering (SRS) and cross-beam energy transfer (CBET) in megajoule-scale direct-drive NIF* targets

- SRS plays an important role in direct-drive inertial confinement fusion (ICF) experiments on the NIF, and was observed in the particle-in-cell (PIC) modeling for NIF-relevant conditions
- To model large regions of plasma, a wave-based fluid model for SRS has been added to the multidimensional laser-plasma simulation environment (*LPSE*) platform
- In *LPSE* simulations, SRS leads to the reduction of the backward-going light driven by CBET

*NIF: National Ignition Facility

Collaborators

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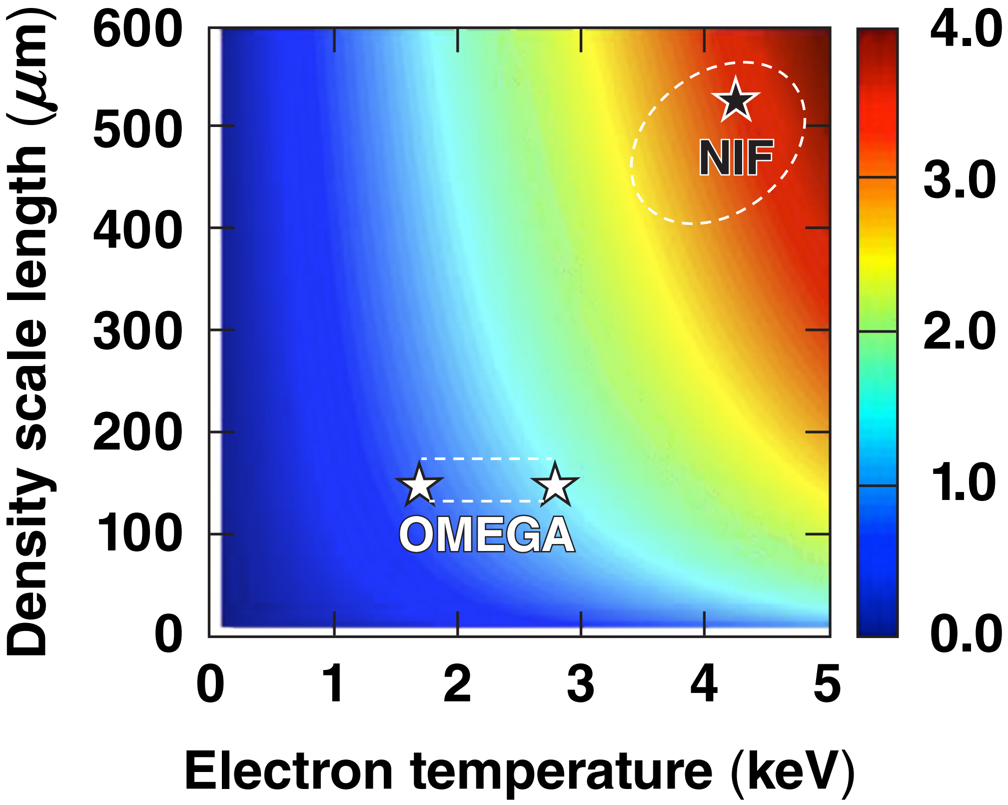
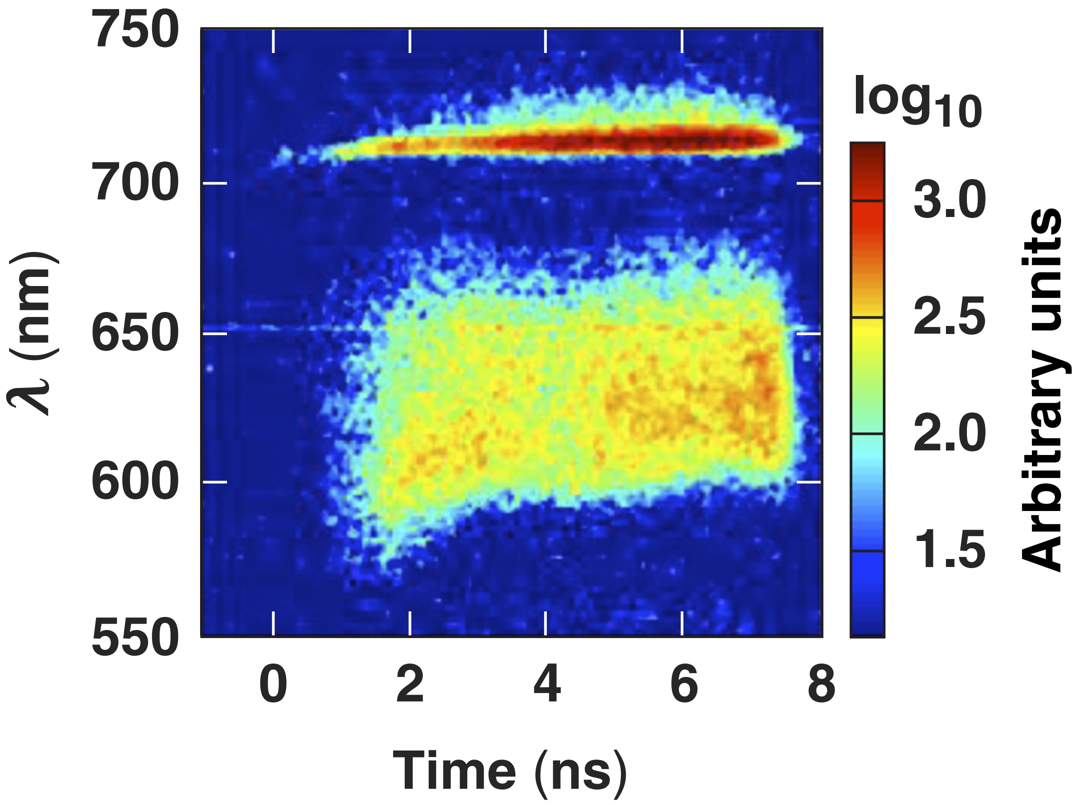
For the parameters relevant to direct-drive NIF plasmas, SRS* has a much lower threshold than the two-plasmon–decay (TPD)** instability

Absolute, single-beam thresholds
$I_{\text{threshold, TPD}}/I_{\text{threshold, SRS}}$



Shot N160420-003
optical spectrometer (SRS)



M. J. Rosenberg *et al.*, presented at the 47th Annual Anomalous Absorption Conference, Florence, OR, 11–16 June 2017.

*C. S. Liu, M. N. Rosenbluth, and R. B. White, Phys. Fluids 17, 1211 (1974).

**A. Simon *et al.*, Phys. Fluids 26, 3107 (1983).

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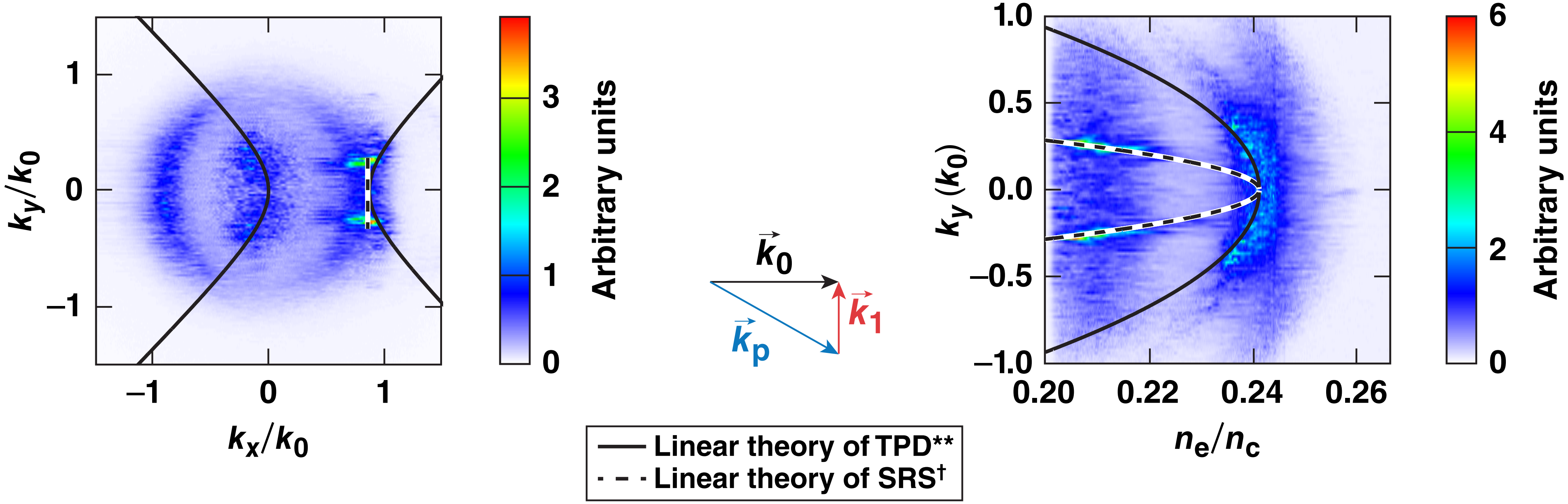
In two-dimensional PIC simulations with *OSIRIS*,* the range of densities over which SRS and TPD are active have been identified

- Incident laser intensity $I = 8 \times 10^{14}$ W/cm^2 (plane wave)
- Density range from 0.20 to 0.27 n_c (density scale length $L = 300$ μm)
- Temperatures $T_e = 4$ keV; $T_i = 2$ keV

The spectra of Langmuir waves in the saturation stage



A. V. Maximov *et al.*, presented at the 58th Annual Meeting of the APS Division of Plasma Physics, San Jose, CA, 31 October–4 November 2017.

*R. A. Fonseca *et al.*, in *Computational Science – ICCS 2002*, edited by P. M. A. Sloot *et al.*, Lecture Notes in Computer Science, Vol. 2331 (Springer, Berlin, 2002), pp. 342–351.

**A. Simon *et al.*, Phys. Fluids 26, 3107 (1983).

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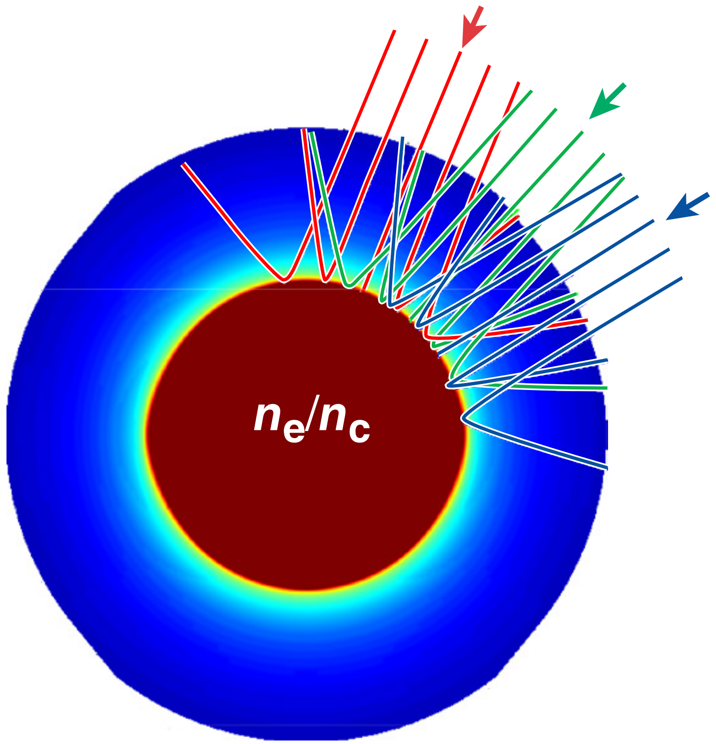
*LPSE** models the LPI** relevant to ICF, resolving scales from laser wavelength to target size

- *LPSE*
  - is non-paraxial
  - models full vector fields
  - has arbitrary field injection
  - has spectral bandwidth models
  - uses different density and flow profiles
  - includes multilevel parallelism

- *LPSE* is capable of modeling multiple LPI processes
  - stimulated Brillouin scattering (SBS)
  - CBET
  - filamentation
  - two-plasmon decay
  - Langmuir decay instability (LDI)
  - hot-electron generation



*J. F. Myatt *et al.*, Phys. Plasmas 24, 056308 (2017).
**LPI: laser–plasma interaction

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LPSE now includes the capabilities to model SRS

- The model describes the evolution of laser light E_0 (near frequency ω_0), Raman-scattered light E_1 (near ω_1), plasma-wave field E_p (near ω_p), and the ion-acoustic perturbation N

Laser light: $$i\frac{\partial \vec{V}_0}{\partial t} + i\gamma_0 \circ \vec{V}_0 + \frac{c^2}{2\omega_0}\vec{\nabla}^2 \vec{V}_0 + \frac{\omega_0^2 - \omega_p^2(1+N)}{2\omega_0}\vec{V}_0 = \frac{i\omega_p}{4\omega_0}\left(\vec{\nabla}\cdot\vec{V}_p\right)\vec{V}_1$$

Raman light: $$i\frac{\partial \vec{V}_1}{\partial t} + i\gamma_1 \circ \vec{V}_1 + \frac{c^2}{2\omega_1}\vec{\nabla}^2 \vec{V}_1 + \frac{\omega_1^2 - \omega_p^2(1+N)}{2\omega_1}\vec{V}_1 = \frac{i\omega_p}{4\omega_0}\left(\vec{\nabla}\cdot\vec{V}_p\right)\vec{V}_0$$

Plasma wave: $$i\frac{\partial \vec{V}_p}{\partial t} + i\gamma_L \circ \vec{V}_p + \frac{3v_{T_e}^2}{2\omega_p}\vec{\nabla}^2 \vec{V}_p - \frac{\omega_p}{2}N\vec{V}_p = \frac{1}{\omega_p}\vec{\nabla}\left(\vec{V}_0\cdot\vec{V}_1^*\right)$$

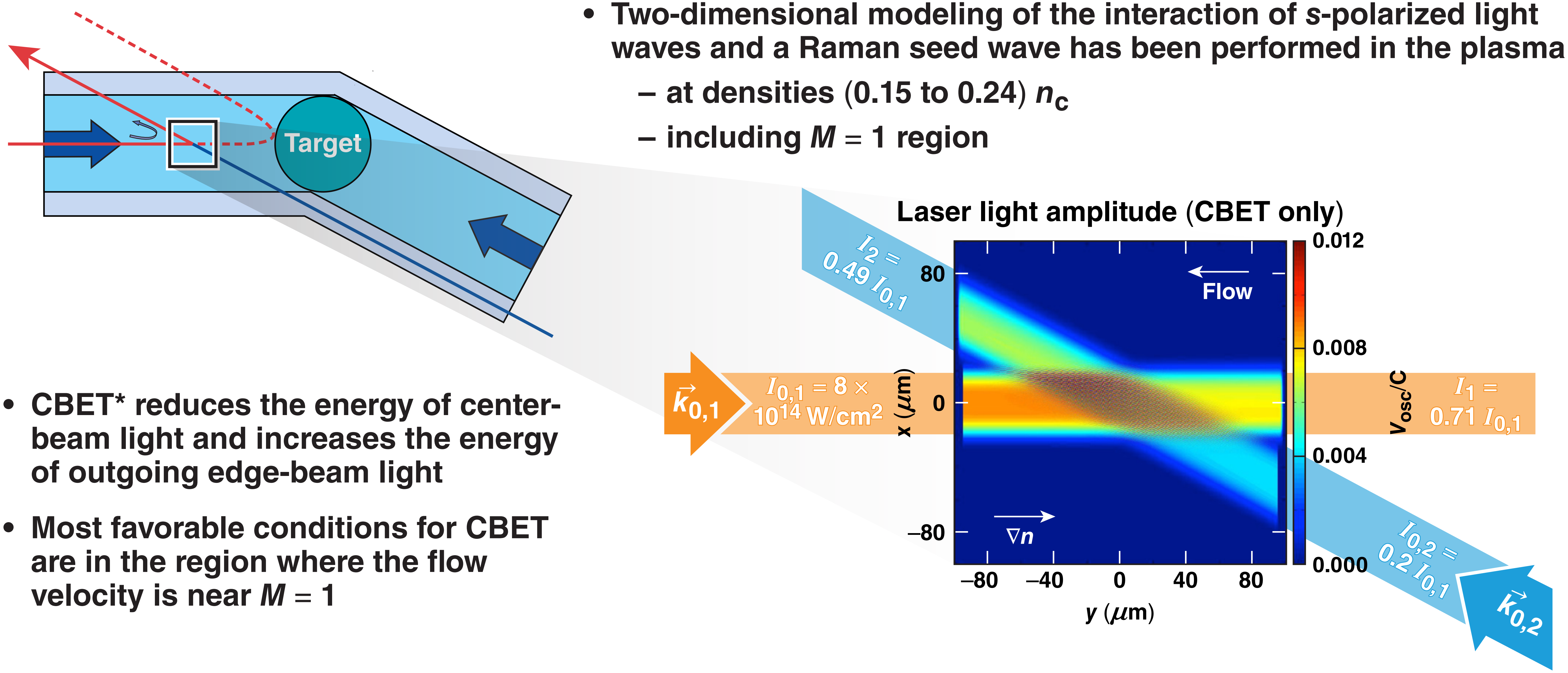
Ion acoustic: $$\frac{\partial^2 N}{\partial \tau^2} + 2\gamma_{ia} \circ \frac{\partial N}{\partial \tau} - c_s^2\vec{\nabla}^2 N = \frac{1}{16\pi n_0 m_i}\vec{\nabla}^2\left[\left|\vec{E}_p\right|^2 + \frac{n_0}{n_c}\left(\left|\vec{E}_0\right|^2 + \frac{\omega_0^2}{\omega_1^2}\left|\vec{E}_1\right|^2\right)\right]$$

where $\vec{V}_j = \frac{ie}{m_e\omega_j}\vec{E}_j, \quad (j = 0, 1, p)$ $\qquad \frac{\partial}{\partial \tau} = \frac{\partial}{\partial t} + \vec{U}_0\cdot\vec{\nabla}, \quad \vec{U}_0$ - flow

It is possible to study relative importance of different wave-coupling processes.

CBET strongly influences the balance of absorbed and scattered laser power

- Two-dimensional modeling of the interaction of *s*-polarized light waves and a Raman seed wave has been performed in the plasma
  - at densities (0.15 to 0.24) n_c
  - including M = 1 region



- CBET* reduces the energy of center-beam light and increases the energy of outgoing edge-beam light
- Most favorable conditions for CBET are in the region where the flow velocity is near M = 1

* I. V. Igumenshchev *et al.*, Phys. Plasmas 17, 122708 (2010).

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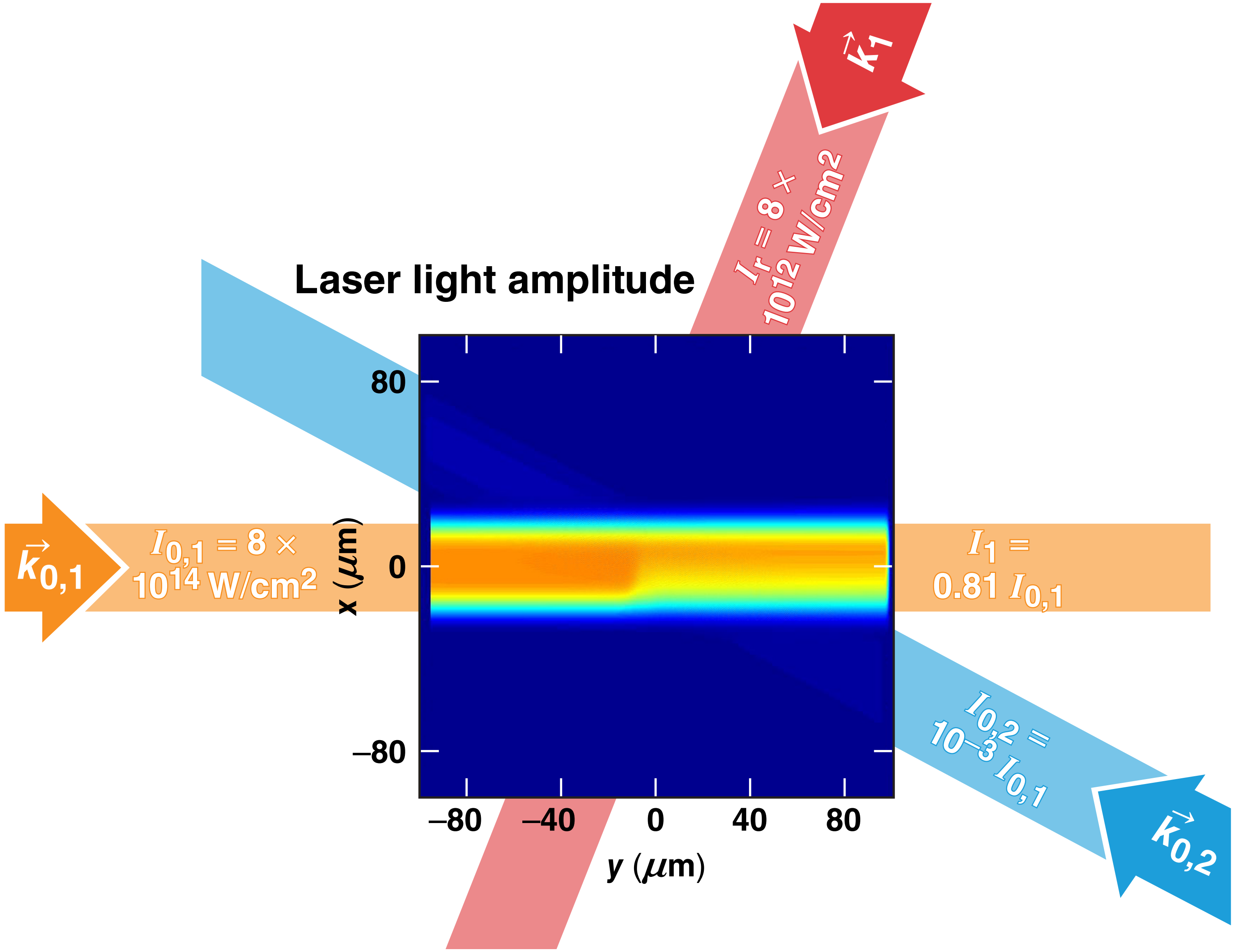
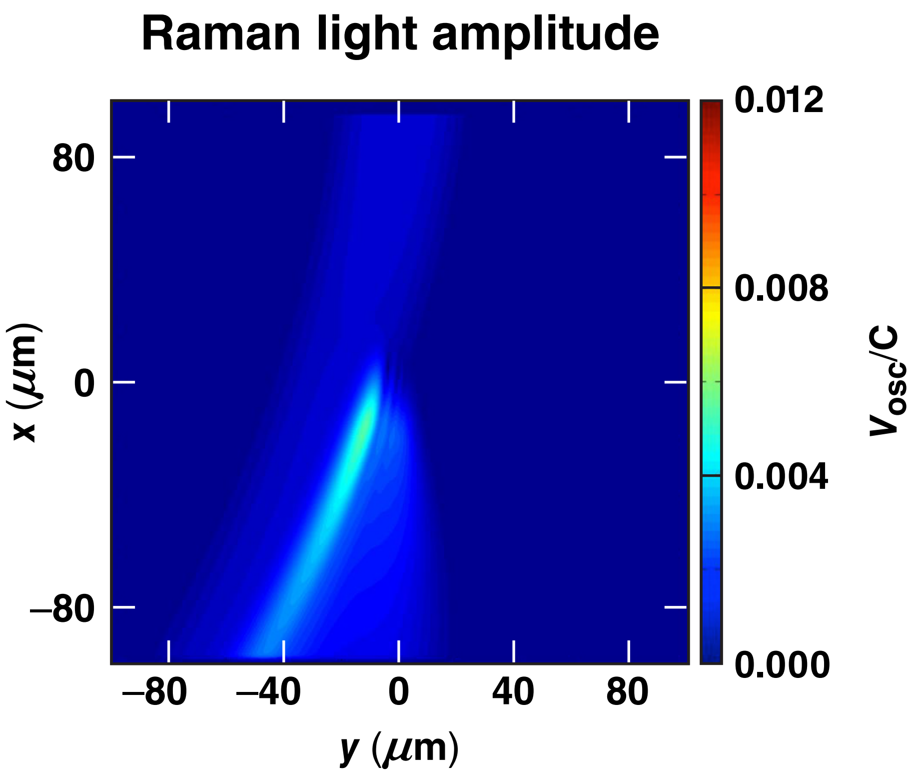
The growth of SRS has been modeled in 2-D wave-based *LPSE* simulations





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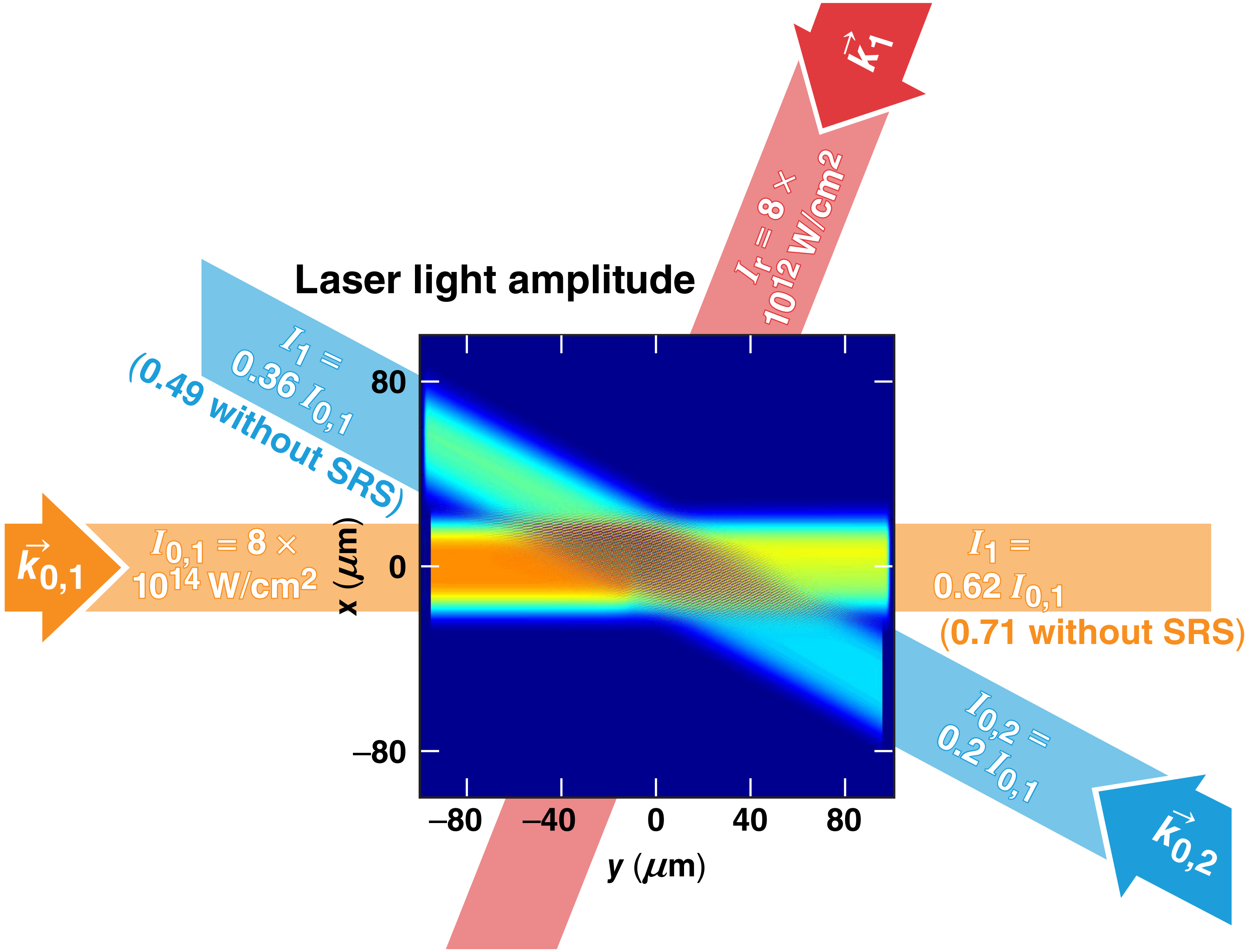
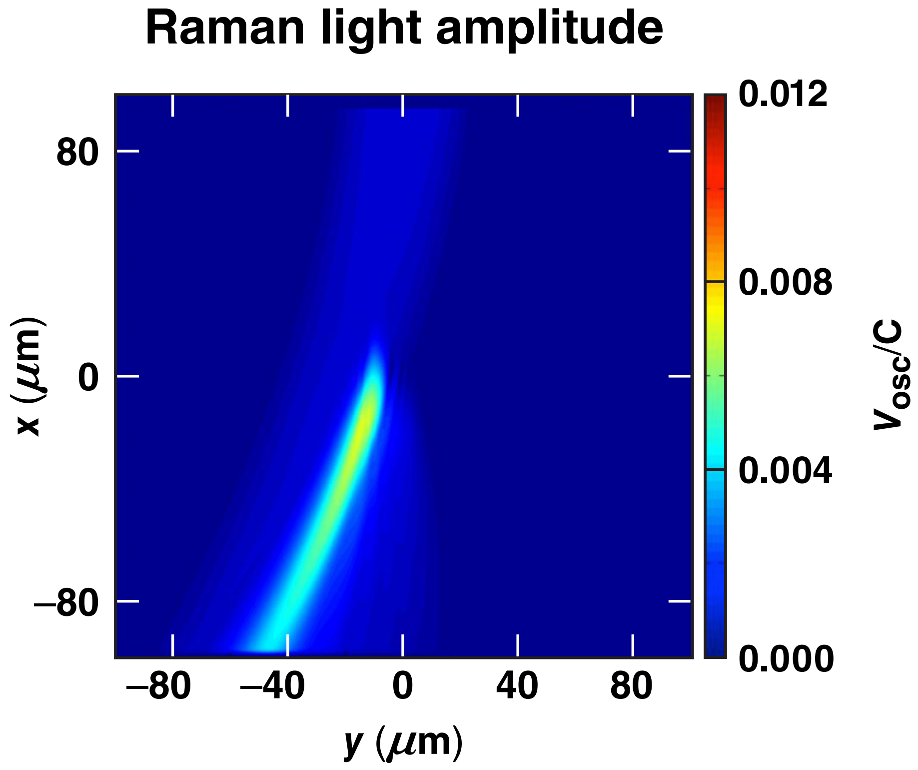
The interplay of SRS and CBET has been studied in 2-D wave-based *LPSE* simulations

Forward-going light is depleted because of both SRS and CBET.

Backward-going light driven by CBET is reduced because of SRS.





TC13946

A new wave-based model has been used to examine the interplay between stimulated Raman scattering (SRS) and cross-beam energy transfer (CBET) in megajoule-scale direct-drive NIF* targets

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