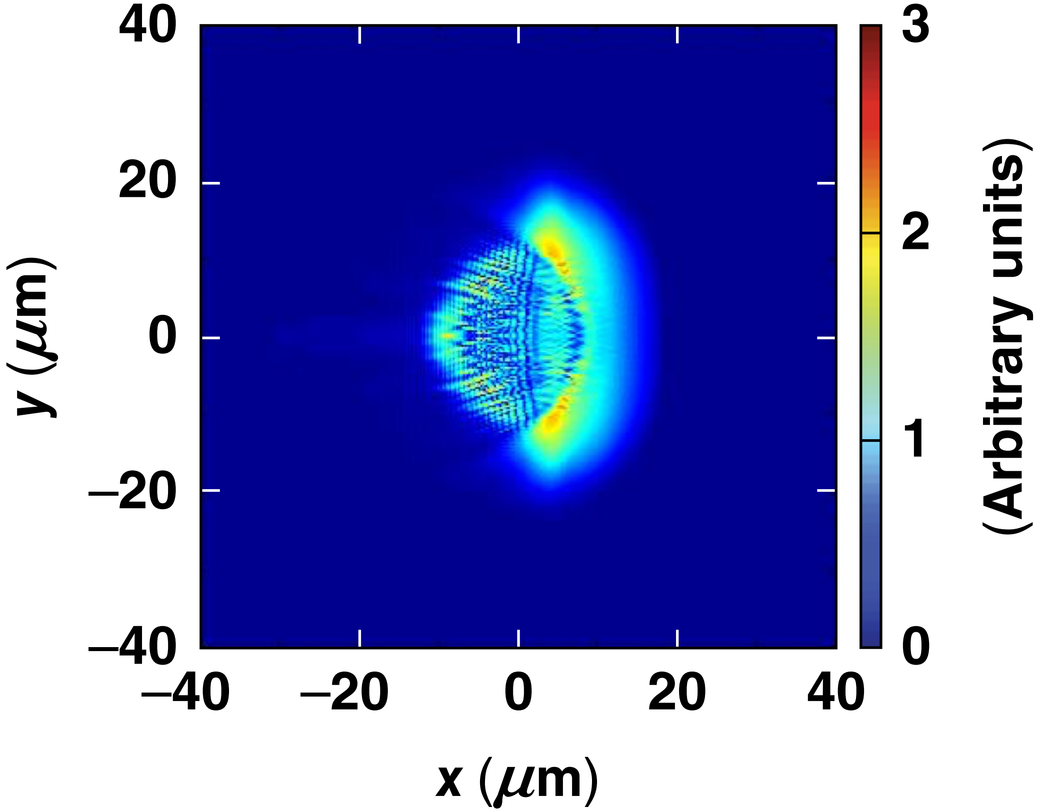
Modeling of Stimulated Raman Scattering in Inhomogeneous Plasmas for Conditions Relevant to the National Ignition Facility

The plasma wave amplitude in 2-D SRS simulations



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Summary

Stimulated Raman scattering (SRS) evolution and saturation has been studied with *LPSE** and the modeling can be expanded to large spatial scales

- **Recent studies of SRS, have motivated the development of the SRS model in *LPSE*, where it is coupled to other *LPSE* capabilities**
- **The growth of the absolute SRS instability has been observed in *LPSE* simulations near the quarter-critical density, with the instability saturation caused by the coupling of SRS to low-frequency density perturbations**
- **In the saturation regime of the absolute SRS instability, the nonlinear dynamic evolution results in a high transmission of laser light through the instability region**

*LPSE: laser-plasma simulation environment; J. F. Myatt *et al.*, Phys. Plasmas 24, 056308 (2017).

In recent direct-drive experiments on the NIF,* the scattered-light spectra have been identified with SRS,** emphasizing the interest in SRS

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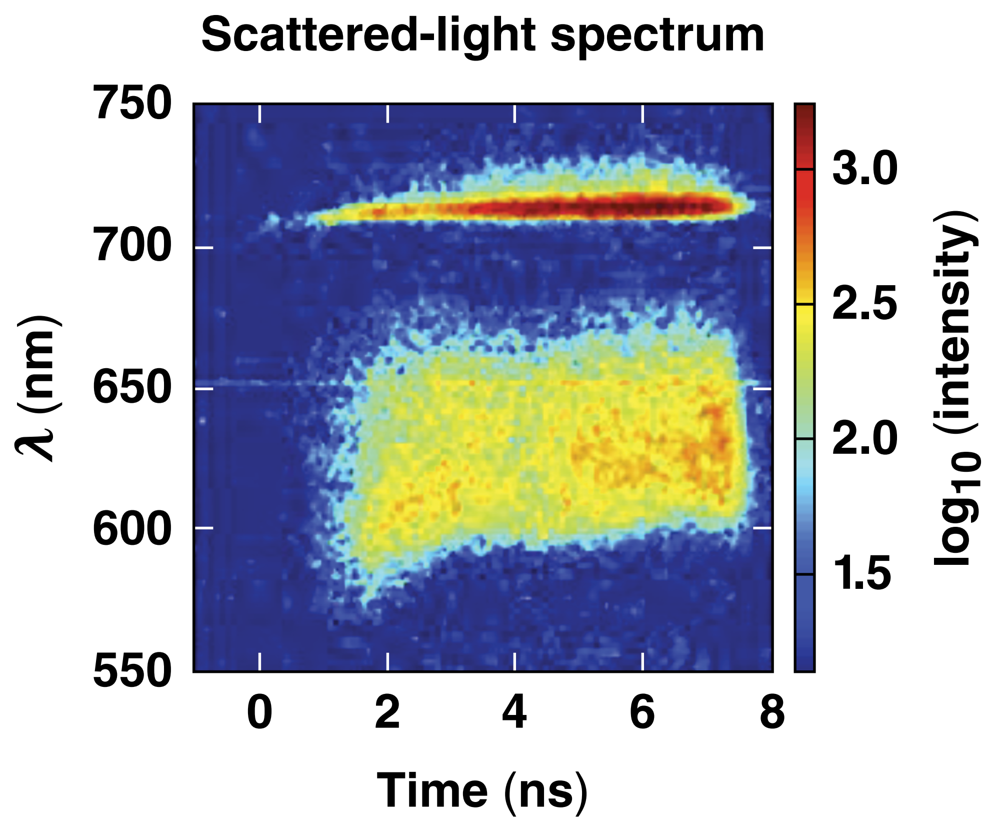
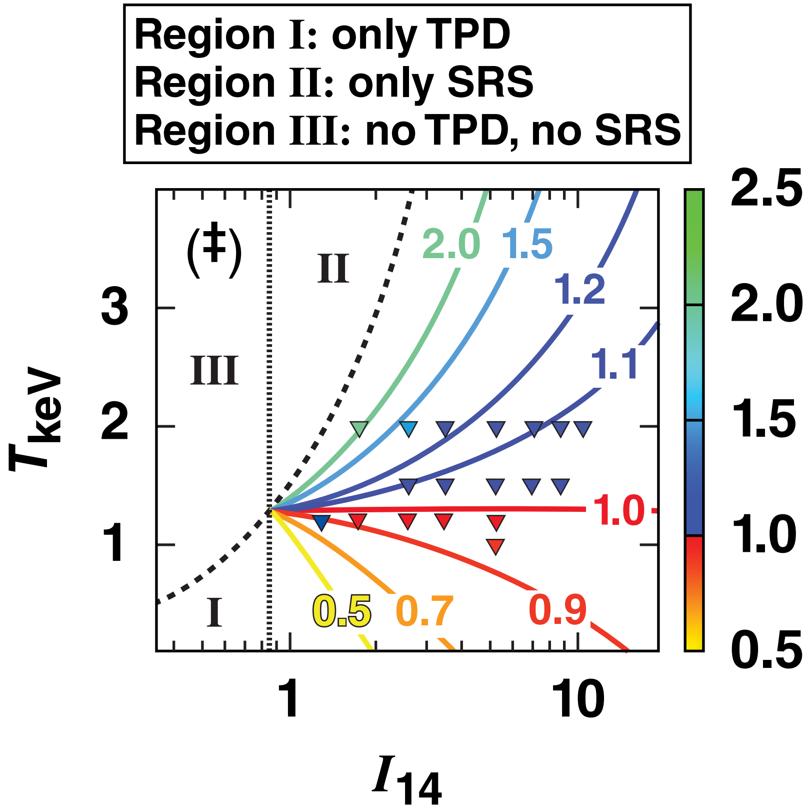
- SRS is the decay of the light wave into the scattered Raman light wave and the plasma wave that can result in
  - absolute instability†
  - convective amplification (Rosenbluth gain in inhomogeneous plasmas)
- SRS develops at densities up to the quarter-critical density, and near the quarter-critical density can coexist with two-plasmon decay (TPD)



*NIF: National Ignition Facility
**M. J. Rosenberg *et al*., Phys. Rev. Lett. 120, 055001 (2018).
†J. F. Drake and Y. C. Lee, Phys. Rev. Lett. 31, 1197 (1973); C. S. Liu, M. N. Rosenbluth, and R. B. White, Phys. Fluids 17, 1211 (1974).

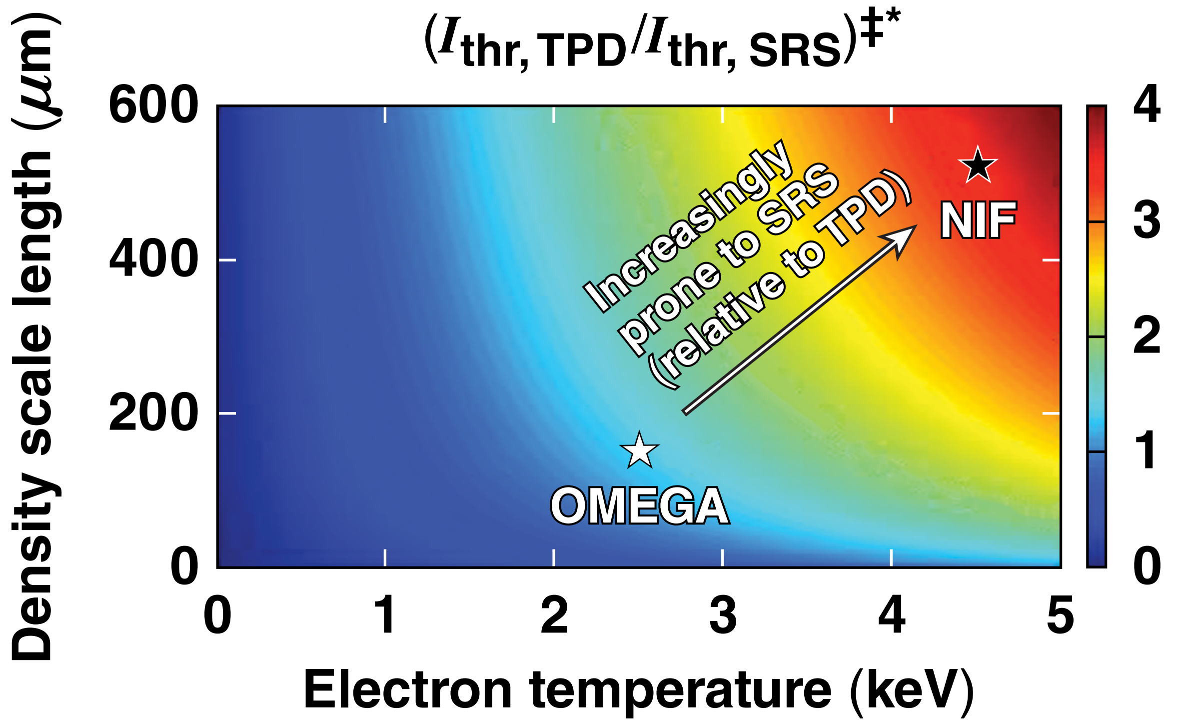
TC14333

For a broad range of direct-drive ICF* plasma conditions near the quarter-critical density, the SRS** growth rate is larger than the TPD† growth rate



$$\xi = \frac{\gamma_{SRS}}{\gamma_{TPD}}$$

$L_n = 300\ \mu m$



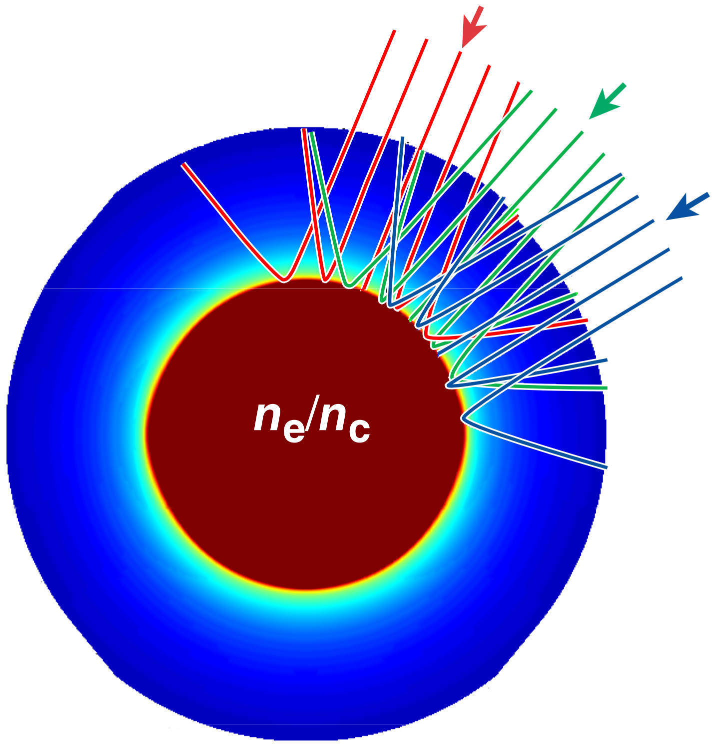
Lines: theory
Points: simulations

*ICF: inertial confinement fusion
**J. F. Drake and Y. C. Lee, Phys. Rev. Lett. 31, 1197 (1973); C. S. Liu, M. N. Rosenbluth, and R. B. White, Phys. Fluids 17, 1211 (1974).
†A. Simon et al., Phys. Fluids 26, 3107 (1983).
‡H. Wen et al., Phys. Plasmas 22, 052704 (2015).
‡*M. J. Rosenberg et al., Phys. Rev. Lett. 120, 055001 (2018).

TC14334

*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)
  - Cross-beam energy transfer (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

TC13942

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

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

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

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

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

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

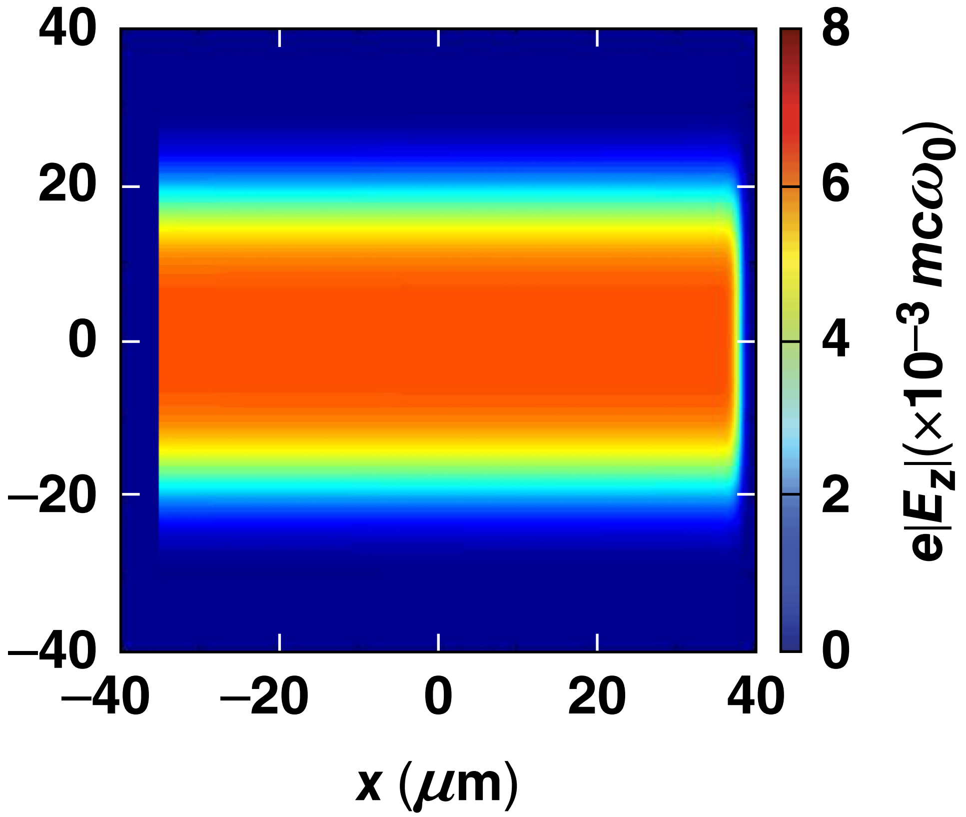
TC13938

The absolute instability of SRS has been modeled in 2-D in the density region including the quarter-critical density

$I_0 = 4 \times 10^{14}$ W/cm^2
$T_e = 3$ keV
$L_n = 300$ μm

Density range (0.21 to 0.27) n_c

Laser light amplitude

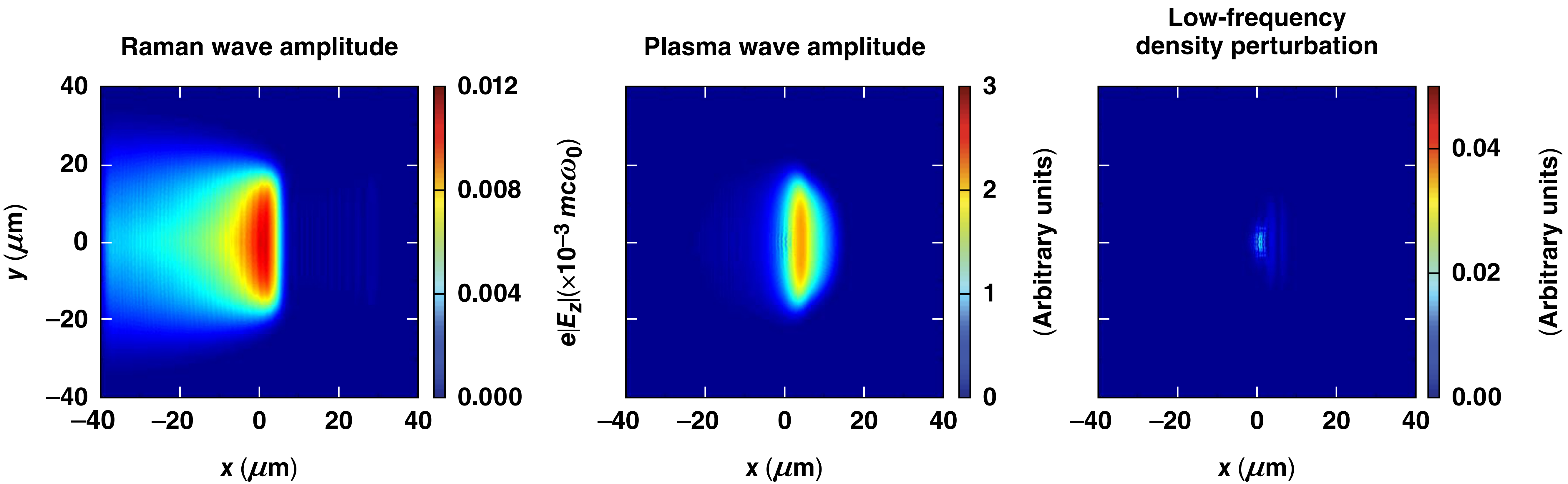


s-polarized light

$t = 1$ ps

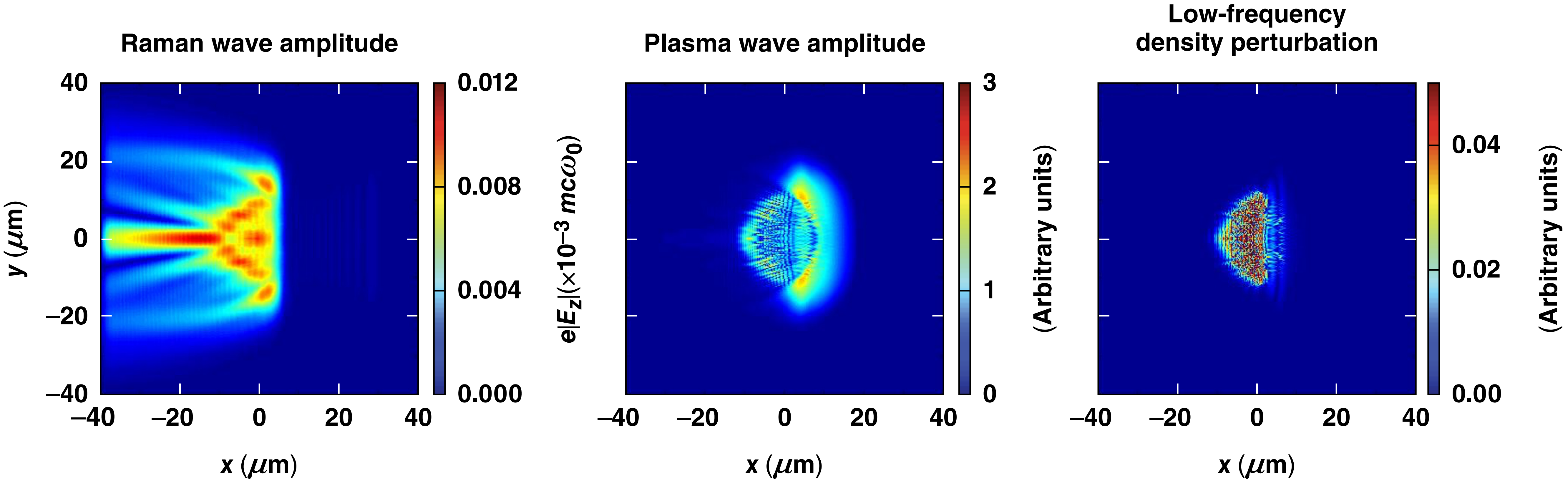
TC14335

The growth of the absolute instability of SRS has been observed



t = 4 ps

The absolute instability growth is followed by the beginning of nonlinear saturation



t = 5 ps

TC14337

The dynamic saturation regime is caused by the coupling between the plasma waves, light waves, and low-frequency modes

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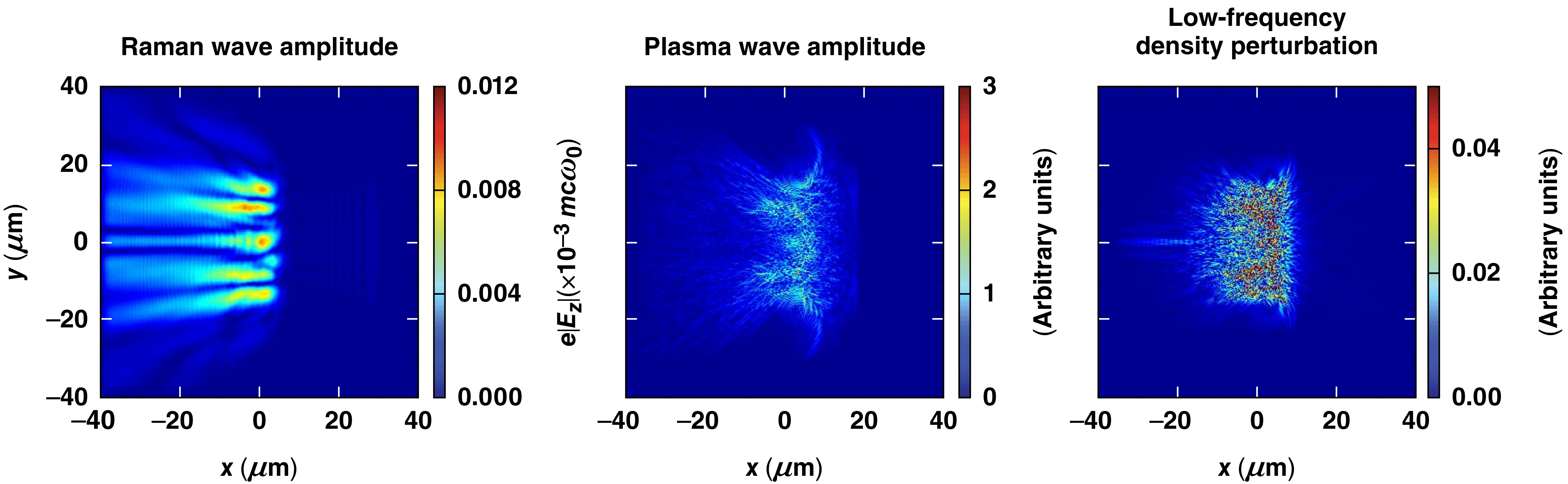
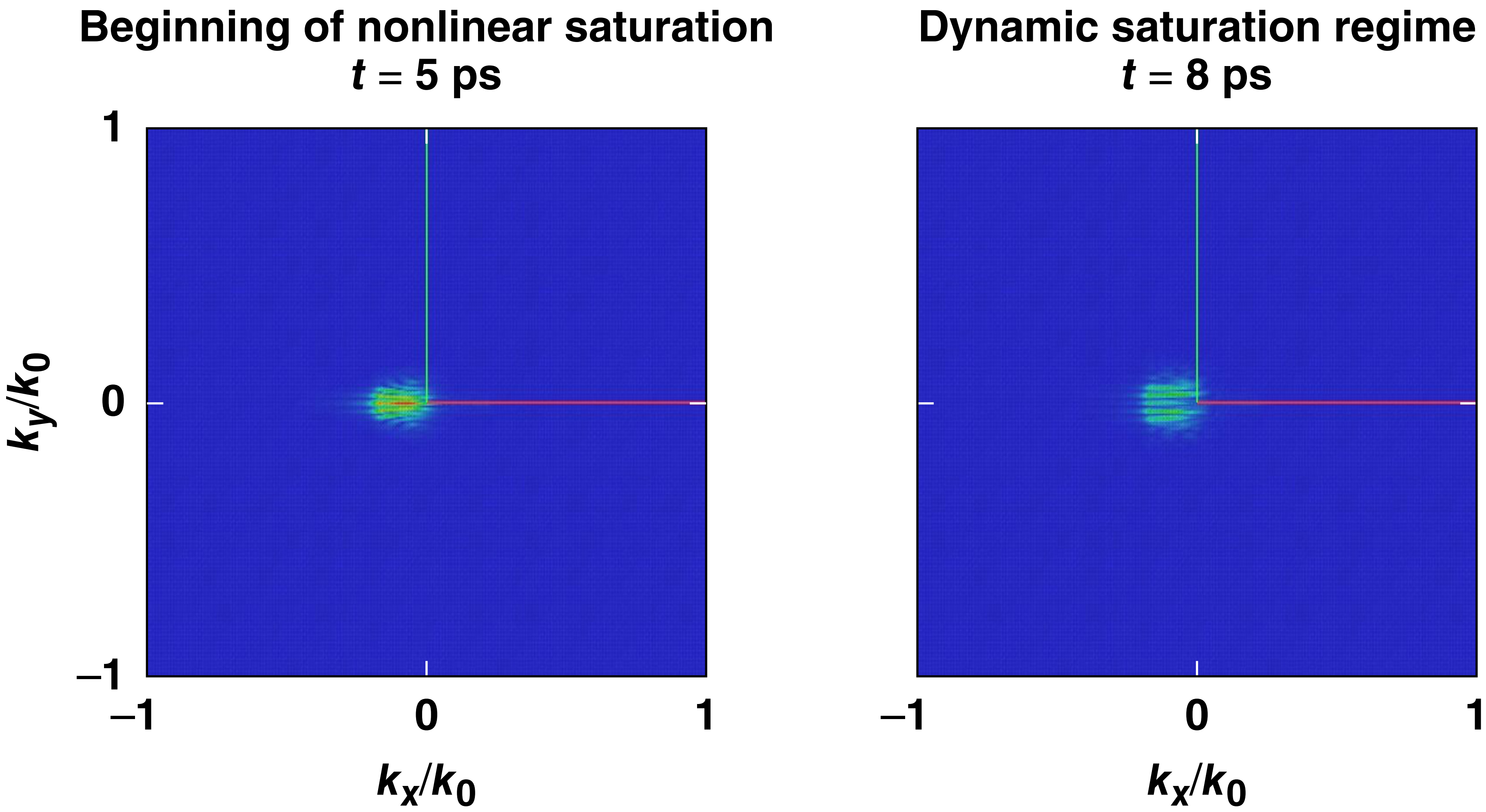


t = 8 ps

The spectra of Raman light correspond to the small wave vector domain



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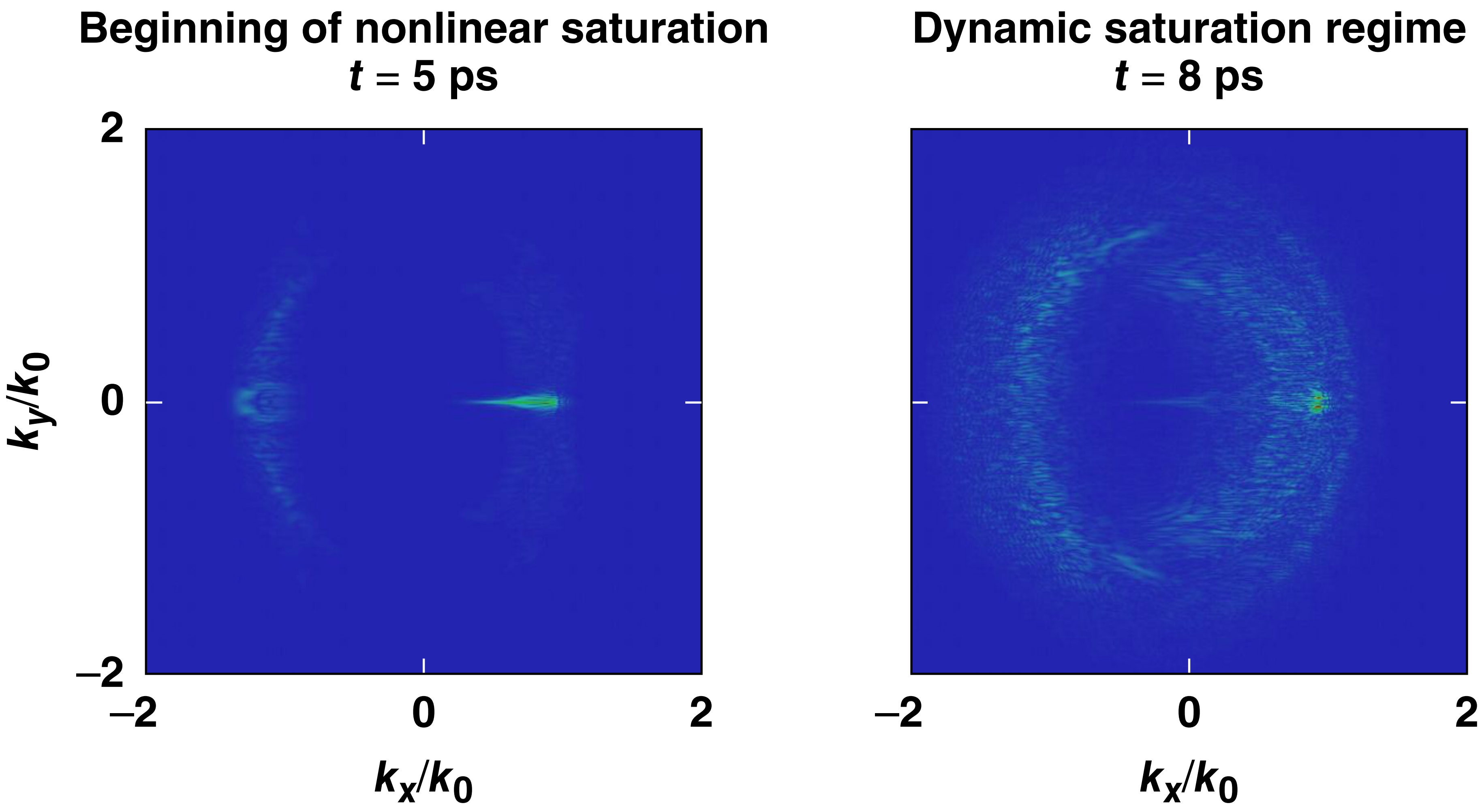
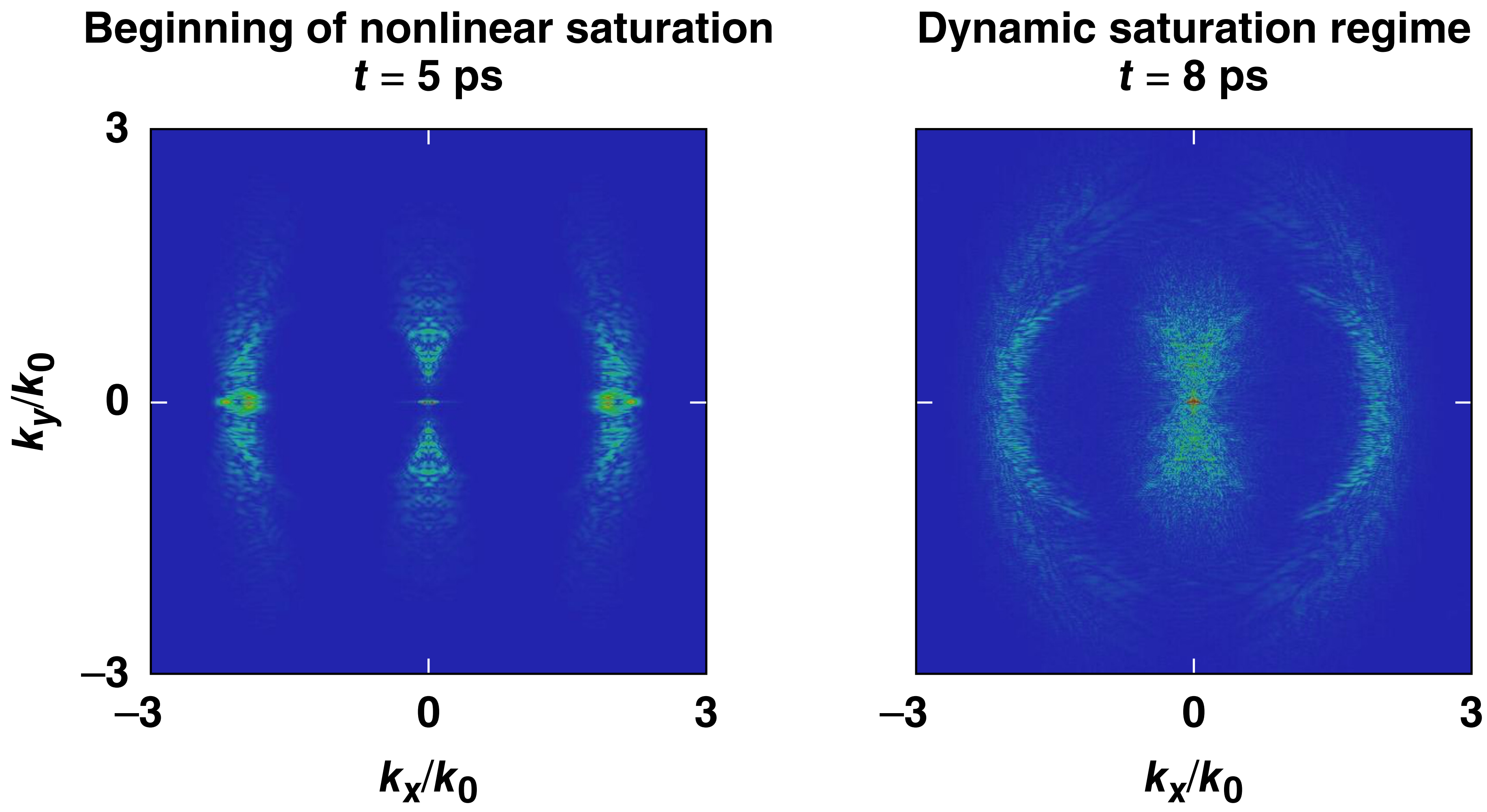
The spectra show the scattering of plasma waves in backwards and other directions



TC14340

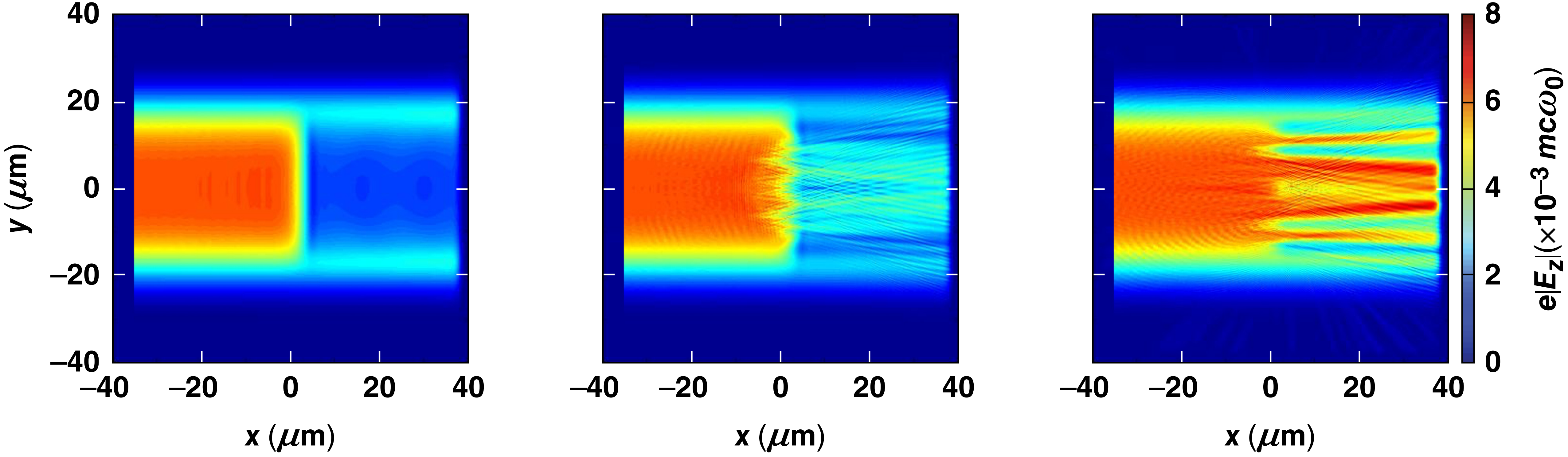
The spectra of low-frequency perturbations show the signatures of Langmuir-decay instability



The laser light is significantly depleted at the end of the instability growth stage, but then the light transmission increases in the dynamic saturation stage

End of instability growth | **Beginning of nonlinear saturation** | **Dynamic saturation regime**

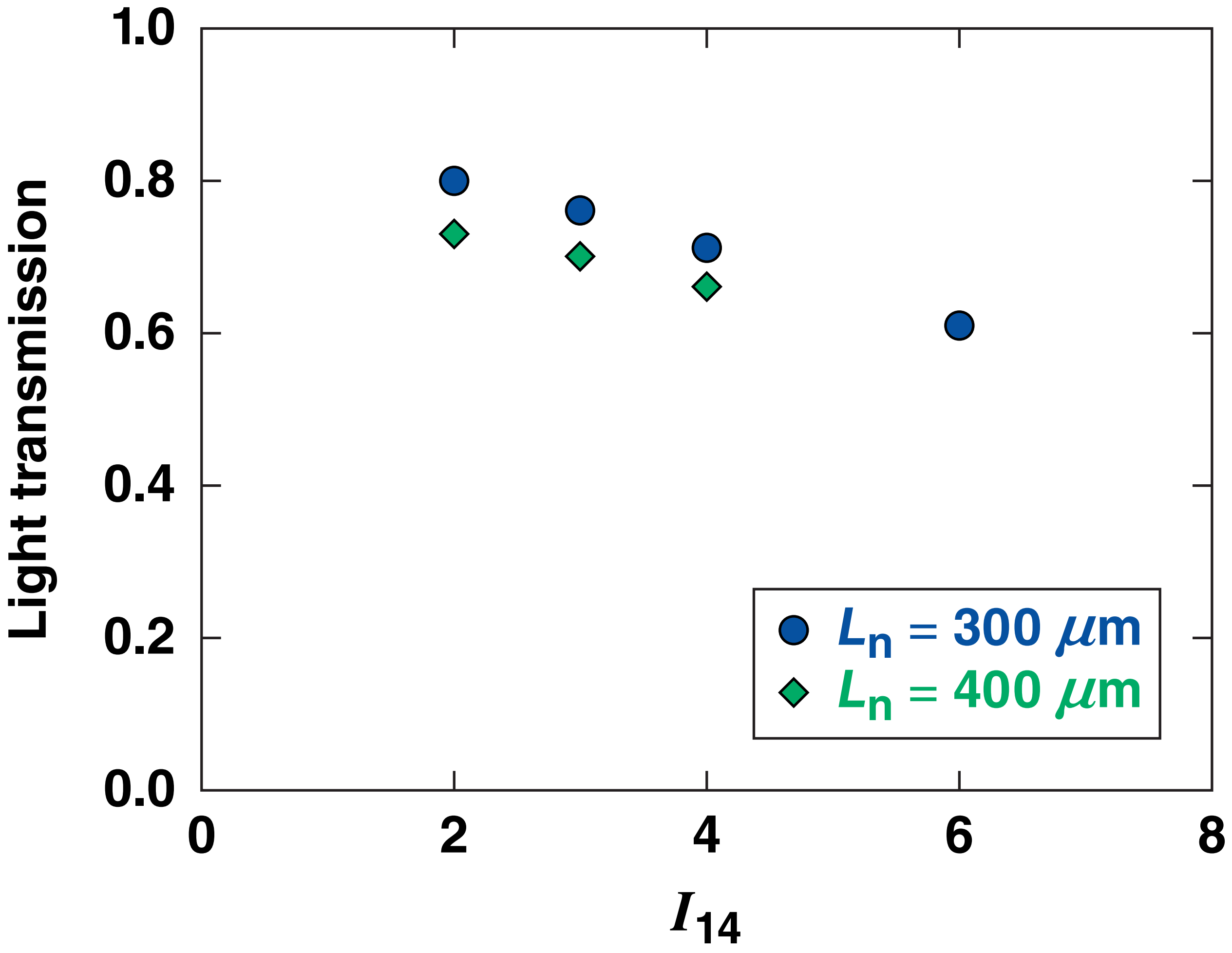
t = 4 ps | t = 5 ps | t = 8 ps



Transmission T = 0.16 | **T = 0.26** | **T = 0.72**

TC14342

The nonlinear-stage transmission of laser light through the SRS instability region moderately depends on laser intensity



Large transmission of laser light explains the coupling of laser light to plasma in the higher-plasma-density region that is consistent with ICF experiments

TC14343

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