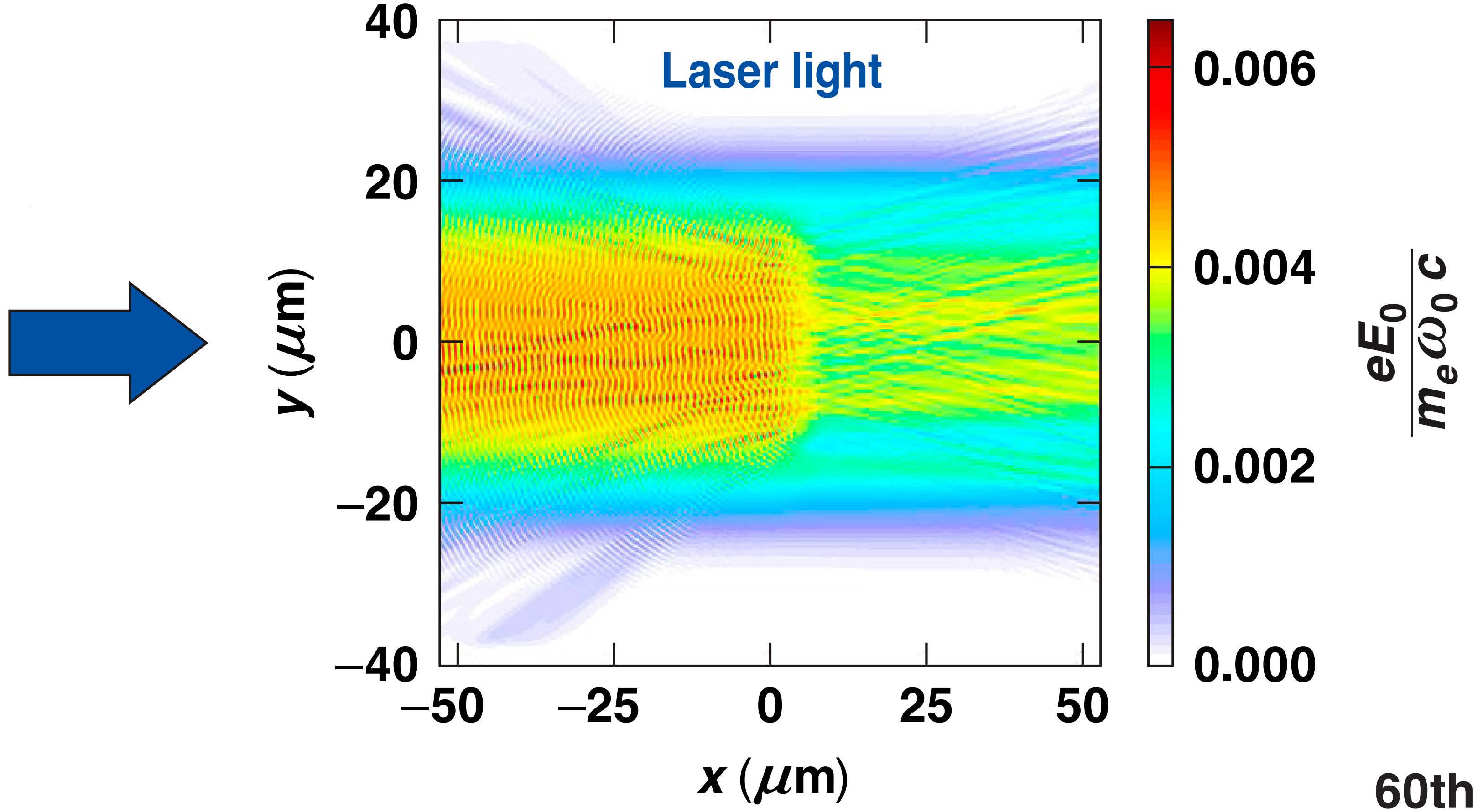
Saturation of Stimulated Raman Scattering in Inhomogeneous Plasmas



A. V. Maximov, J. G. Shaw,
R. W. Short, and J. P. Palastro
University of Rochester
Laboratory for Laser Energetics

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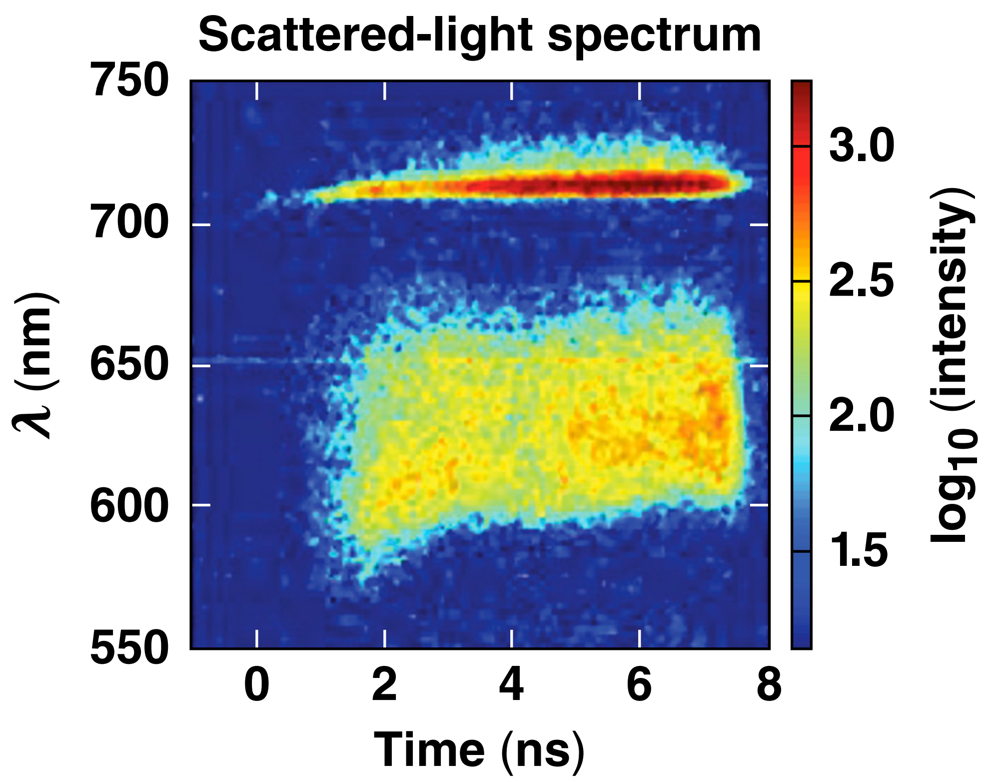
Summary

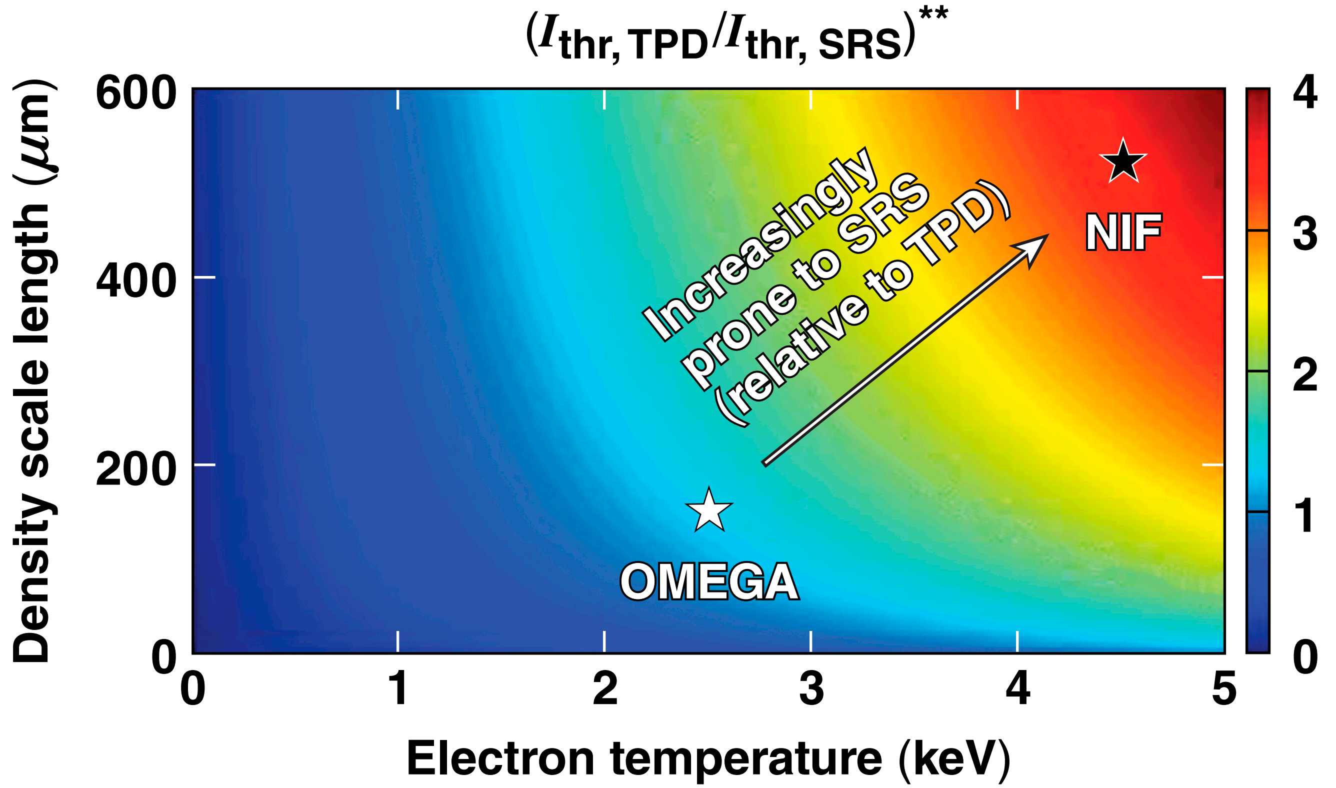
Saturation of the absolute instability of stimulated Raman scattering (SRS) leads to high transmission of laser light through the instability region

- The growth and saturation of the SRS instability near the quarter-critical density has been modeled with laser-plasma simulation environment (*LPSE*)* for the conditions on the National Ignition Facility (NIF)
- The instability saturates dynamically as a result of coupling to incoherent low-frequency density perturbations
- SRS saturation determines the power balance between the transmission of incoherent laser light past the quarter-critical density and the absorption of generated Raman light

*J. F. Myatt *et al.*, Phys. Plasmas 24, 056308 (2017).

Recent direct-drive experiments on the NIF* produced scattered-light spectra consistent with SRS





TPD: two-plasmon decay

*M. J. Rosenberg *et al.*, Phys. Rev. Lett. 120, 055001 (2018).

**A. Simon *et al.*, Phys. Fluids 26, 3107 (1983); J. F. Drake and Y. C. Lee, Phys. Rev. Lett. 31, 1197 (1973).

TC14334b

The experimental observations have motivated the recent addition of SRS to *LPSE*

- **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 δN**

Laser light: $$i\frac{\partial \mathbf{V}_0}{\partial t} + i\gamma_0 \circ \mathbf{V}_0 + \frac{c^2}{2\omega_0}\nabla^2 \mathbf{V}_0 + \frac{\omega_0^2 - \omega_p^2(1 + N_0 + \delta N)}{2\omega_0}\mathbf{V}_0 = \frac{i\omega_p}{4\omega_0}(\nabla \cdot \mathbf{V}_p)\mathbf{V}_1$$

Raman light: $$i\frac{\partial \mathbf{V}_1}{\partial t} + i\gamma_1 \circ \mathbf{V}_1 + \frac{c^2}{2\omega_1}\nabla^2 \mathbf{V}_1 + \frac{\omega_1^2 - \omega_p^2(1 + N_0 + \delta N)}{2\omega_1}\mathbf{V}_1 = \frac{i\omega_p}{4\omega_1}(\nabla \cdot \mathbf{V}_p^*)\mathbf{V}_0$$

Plasma wave: $$i\frac{\partial \mathbf{V}_p}{\partial t} + i\gamma_L \circ \mathbf{V}_p + \frac{3v_{T_e}^2}{2\omega_p}\nabla^2 \mathbf{V}_p - \frac{\omega_p(N_0 + \delta N)}{2}\mathbf{V}_p = \frac{1}{\omega_p}\nabla(\mathbf{V}_1^* \cdot \mathbf{V}_0)$$

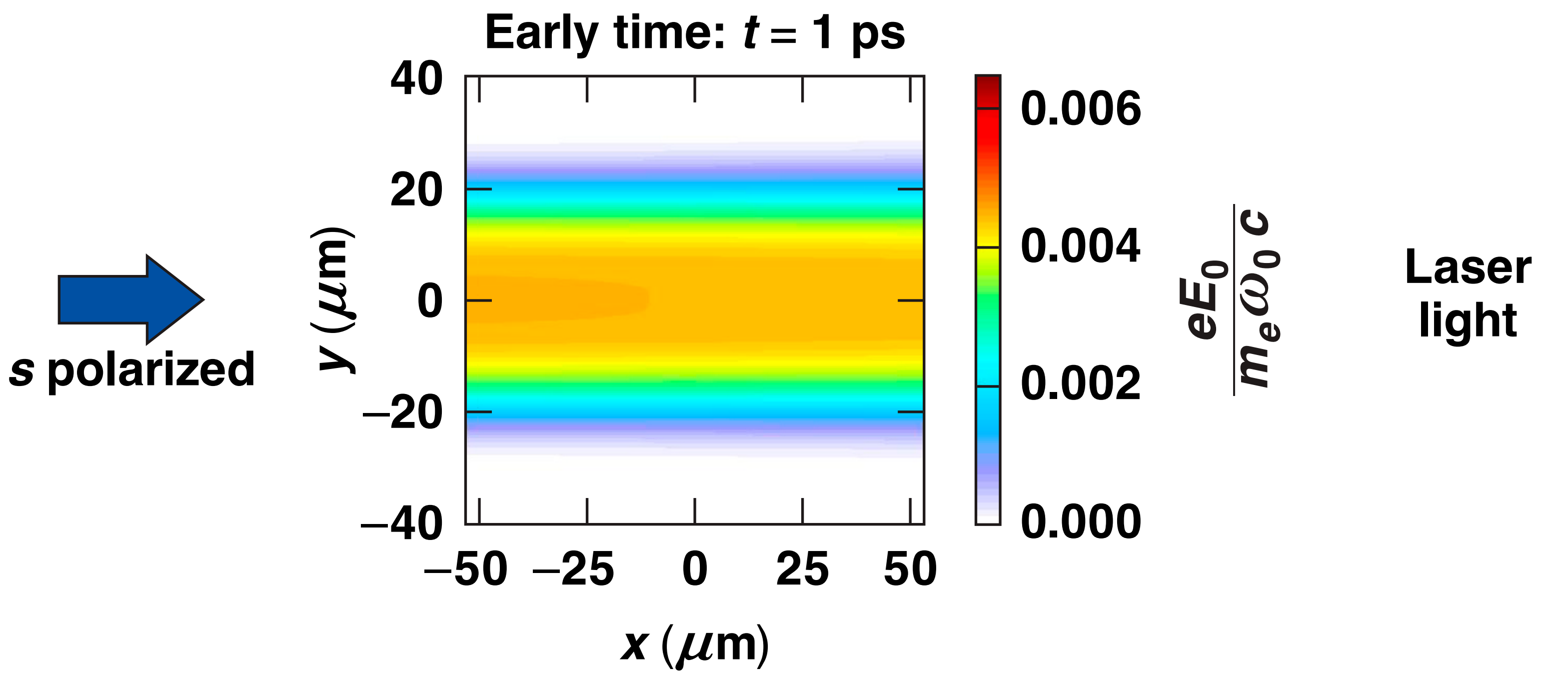
Ion acoustic: $$\frac{\partial^2 \delta N}{\partial \tau^2} + 2\gamma_{ia} \circ \frac{\partial \delta N}{\partial \tau} - c_s^2 \nabla^2 \delta N = \frac{1}{16\pi n_0 m_i}\nabla^2\left[|\boldsymbol{E}_p|^2 + \frac{n_0}{n_c}\left(|\boldsymbol{E}_0|^2 + \frac{\omega_0^2}{\omega_1^2}|\boldsymbol{E}_1|^2\right)\right]$$

where $\boldsymbol{V}_j = \frac{ie\boldsymbol{E}_j}{m_e \omega_j}, \quad (j = 0, 1, \mathrm{p})$ $\qquad \frac{\partial}{\partial \tau} = \frac{\partial}{\partial t} + \boldsymbol{U}_0 \cdot \nabla, \quad \boldsymbol{U}_0$: flow; $\quad N_0$: background density variation

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

TC13938b

Absolute SRS transitions from a coherent pump-depletion stage to a dynamic incoherent saturation stage



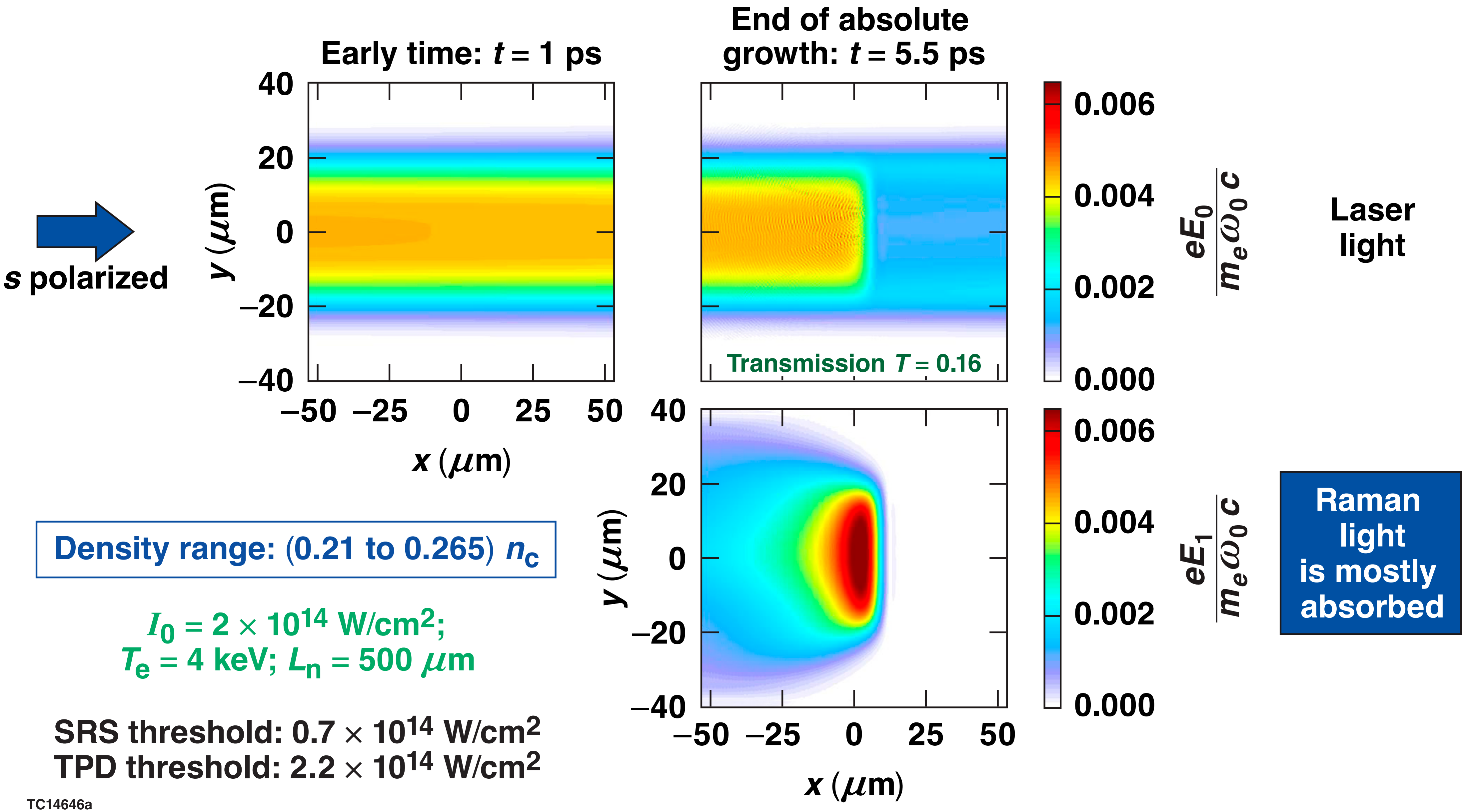
Density range: (0.21 to 0.265) n_c

$I_0 = 2 \times 10^{14}$ W/cm^2;
$T_e = 4$ keV; $L_n = 500$ μm

SRS threshold: 0.7×10^{14} W/cm^2
TPD threshold: 2.2×10^{14} W/cm^2

TC14646b

Absolute SRS transitions from a coherent pump-depletion stage to a dynamic incoherent saturation stage



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TC14646a

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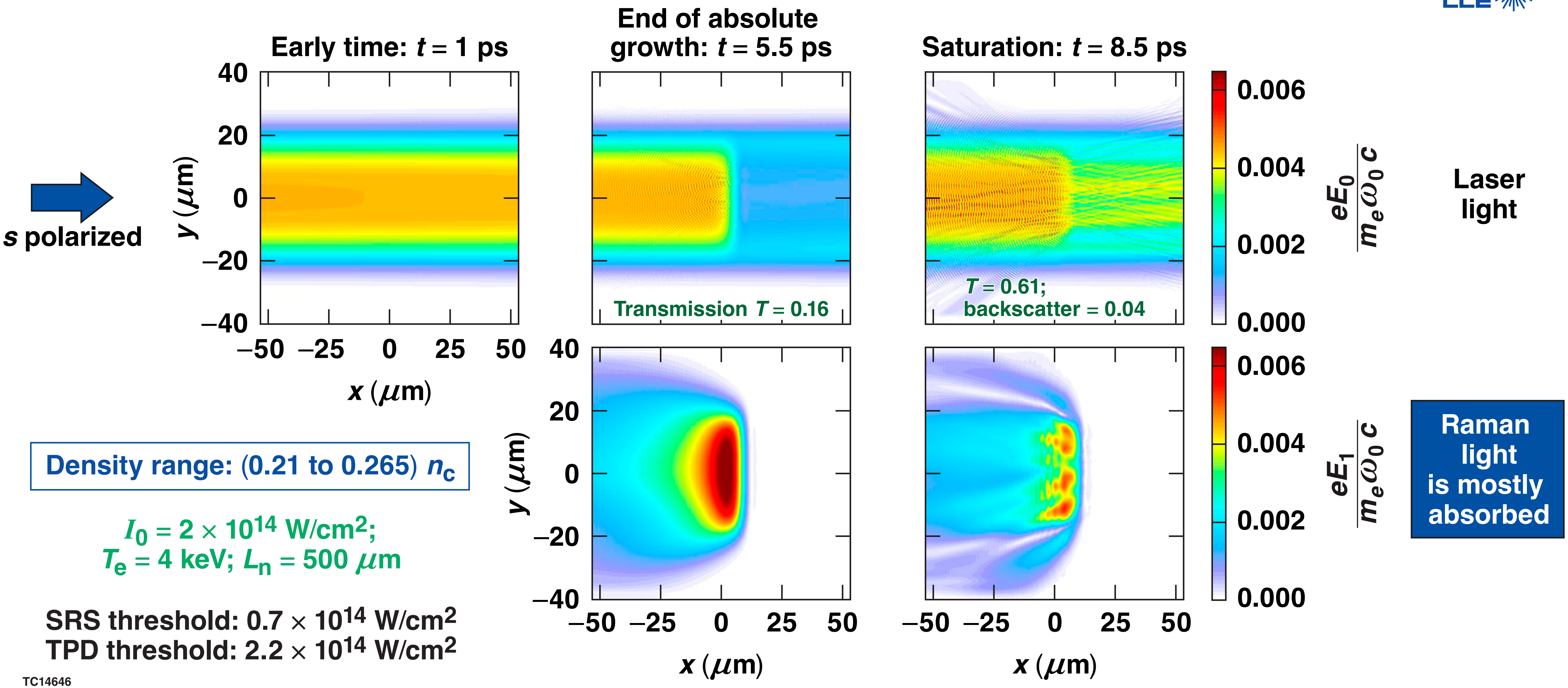

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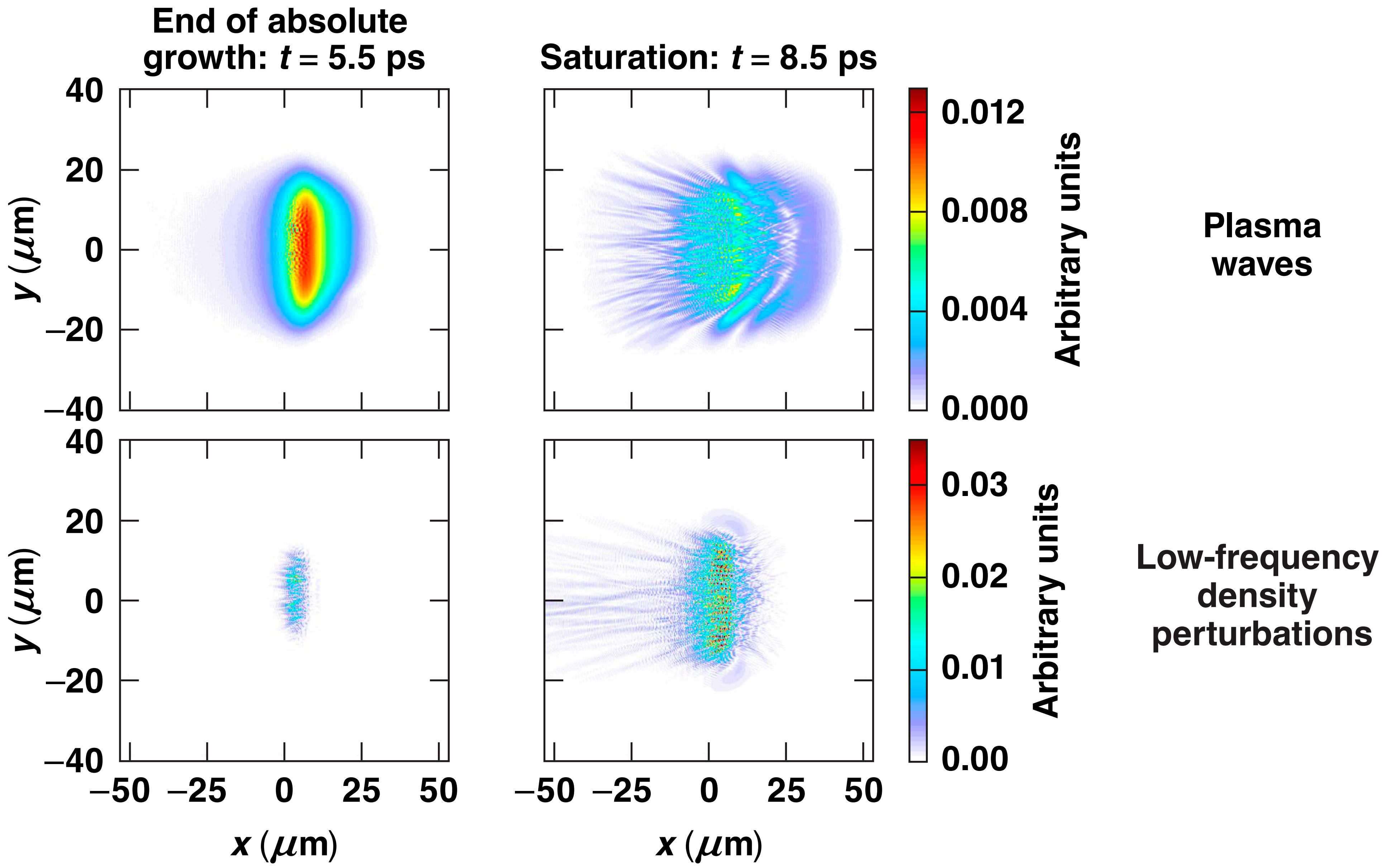
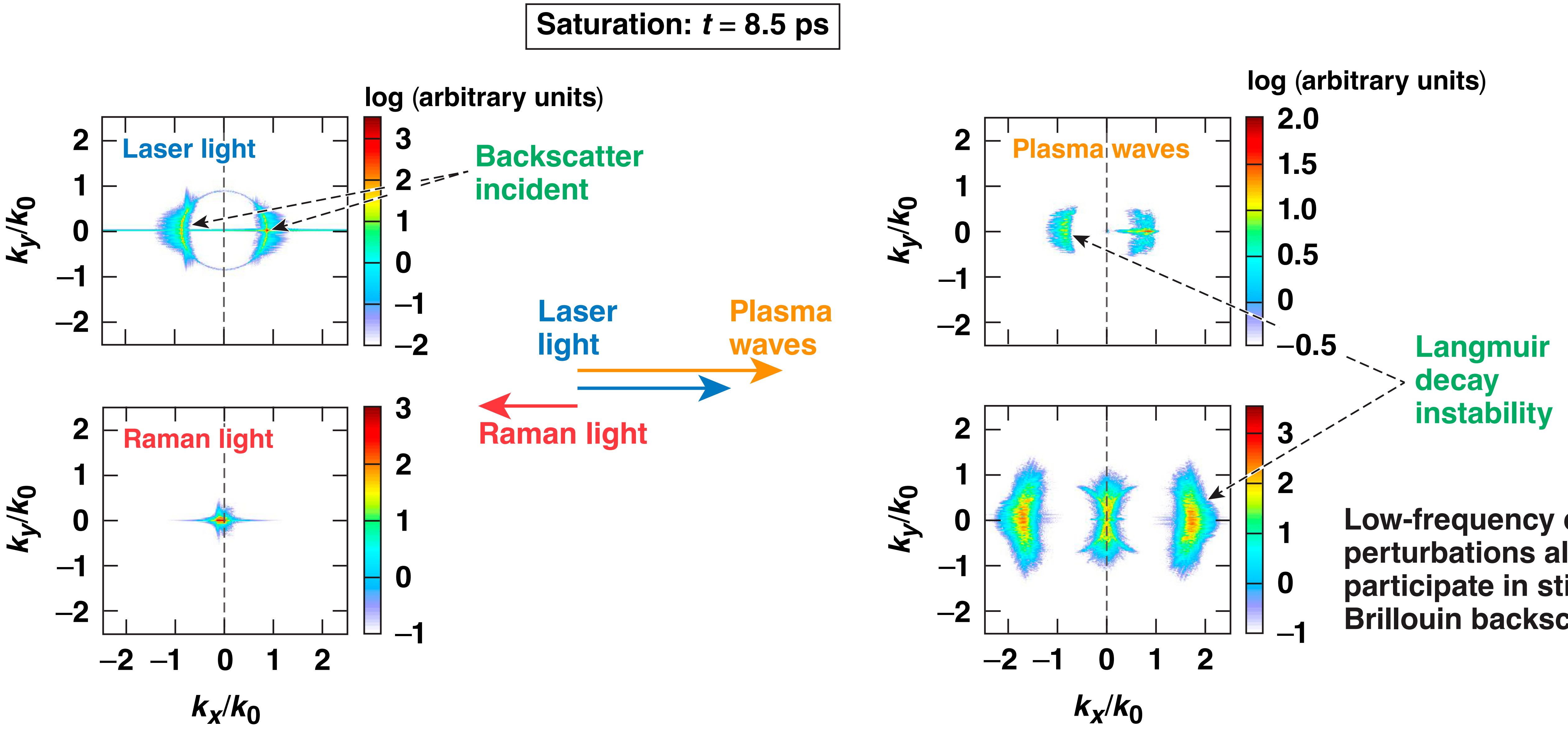
TC14646

The dynamic saturation results from the development of incoherent low-frequency density perturbations



TC14647

Electron plasma waves generated by SRS drive the Langmuir decay instability that amplifies incoherent low-frequency density perturbations



Low-frequency density perturbations also participate in stimulated Brillouin backscattering

TC14648

The transmitted fraction of laser light through the absolute SRS region moderately decreases with increasing laser intensity

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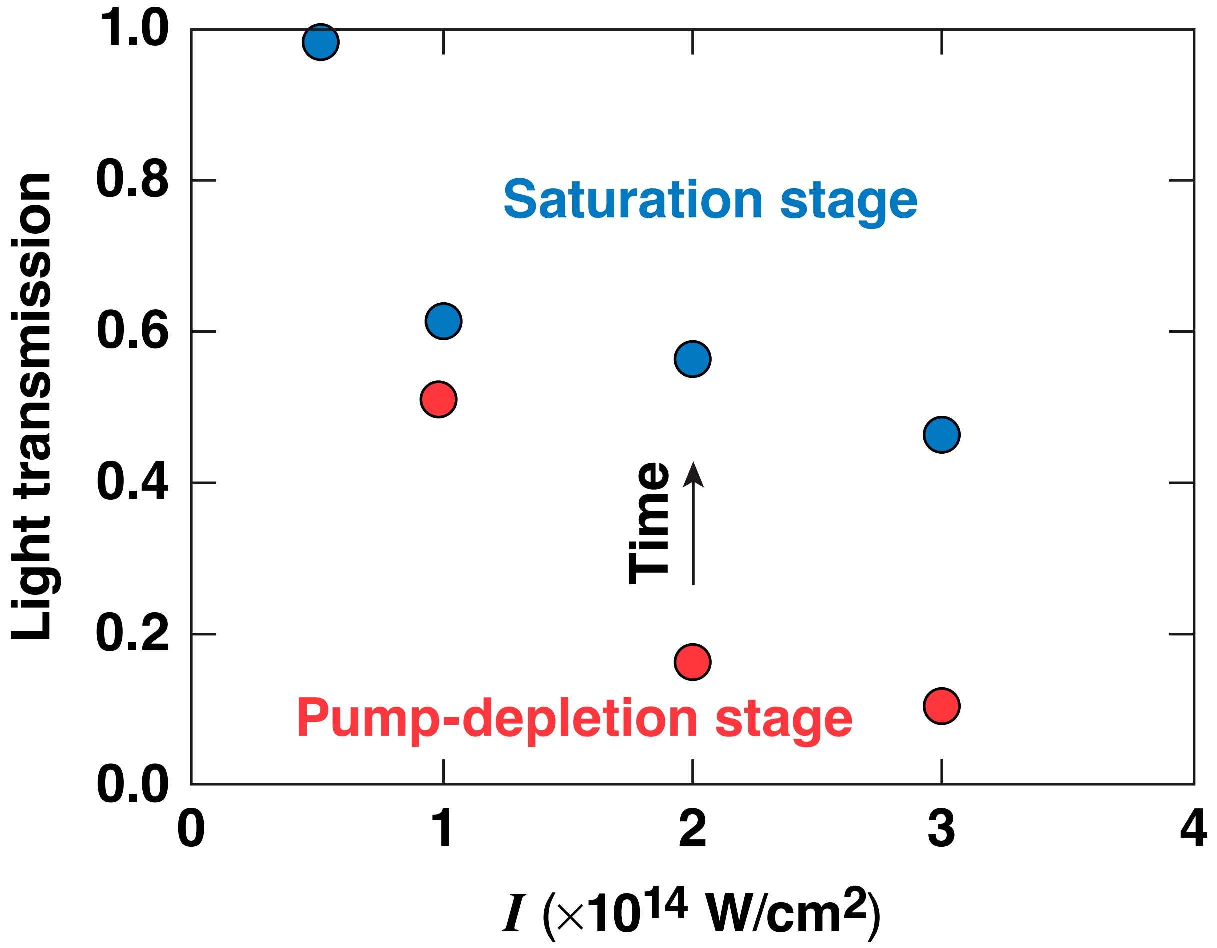
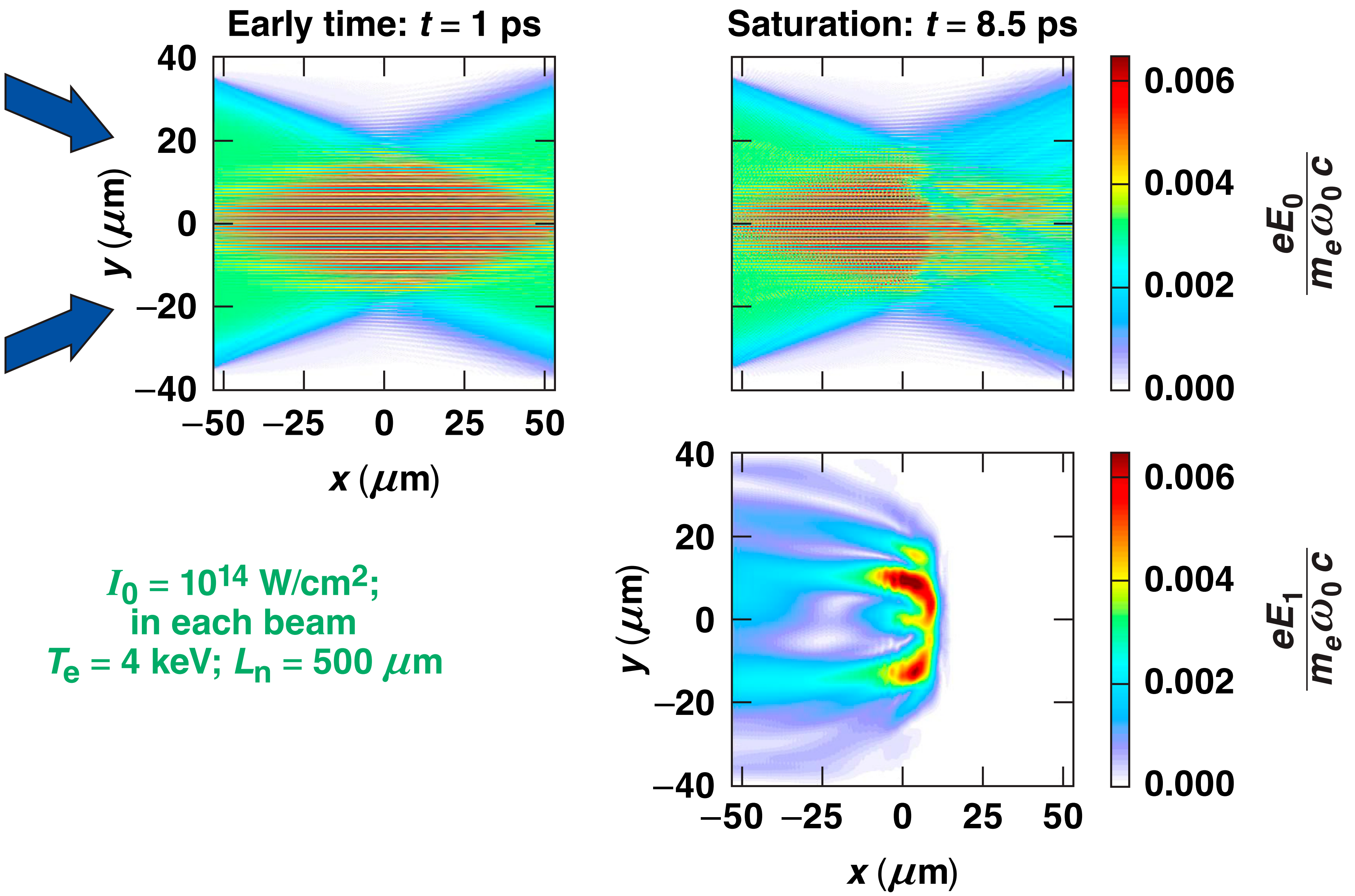


- Transmission of laser light is explained by the incoherence of the forward-going light induced by SRS
- It is consistent with the coupling of laser light to plasmas at higher densities ($\sim n_c$)

TC14649

Two laser beams driving absolute SRS also undergo dynamic saturation



Laser light

Transmission $T = 0.59$;
Backscatter $B = 0.02$

Raman light (common wave driven by two laser beams)

$I_0 = 10^{14}$ W/cm^2;
in each beam
$T_e = 4$ keV; $L_n = 500\ \mu$m

TC14650

Summary/Conclusions

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