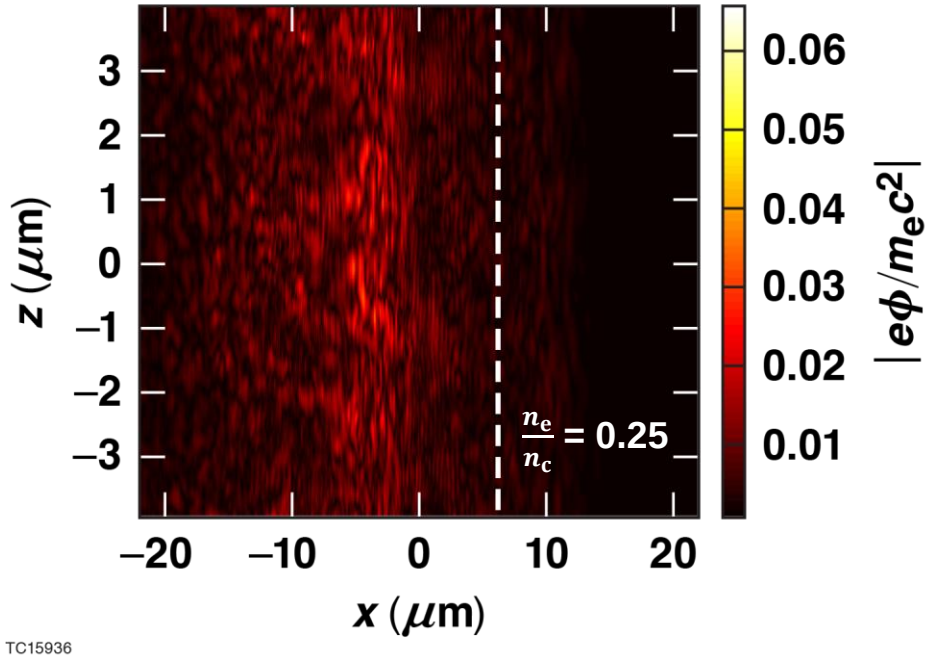
Absorption of Laser Light by Coupling to Incoherent Plasma Waves at Quarter-Critical Density

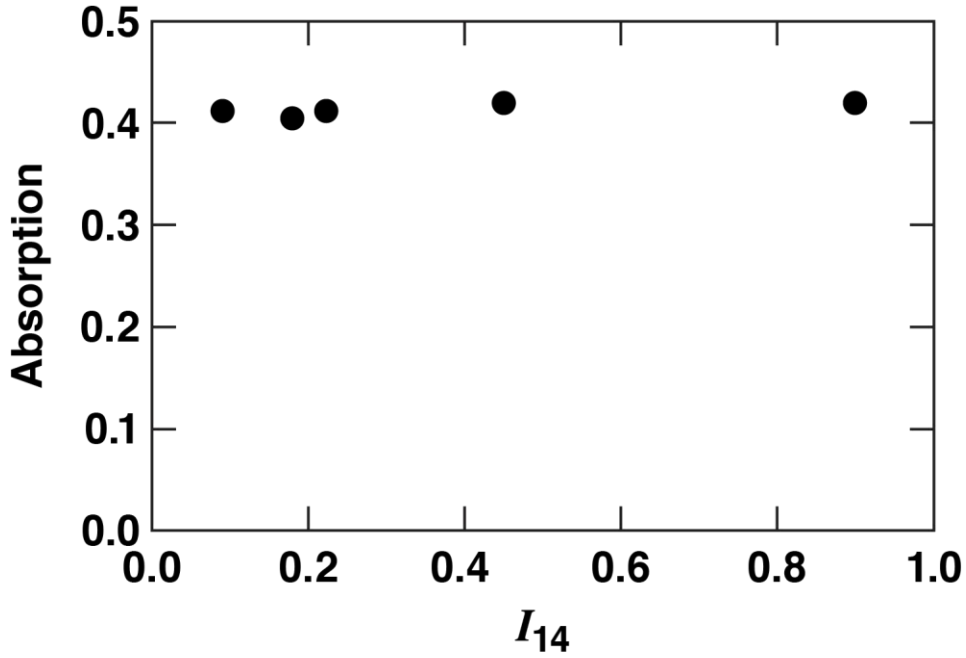
Main laser beam

Probe laser beam

Plasma-wave potential



Absorption of probe beam



A. V. Maximov
University of Rochester
Laboratory for Laser Energetics

63rd Annual Meeting of
the American Physical Society Division of Plasma Physics
Pittsburgh, PA
8–12 November 2021

Summary

An ensemble of incoherent plasma waves enhances the linear absorption of laser light through the region near quarter-critical density

- Near quarter-critical density in a plasma, an incident laser photon can decay into two plasmons, driving the two-plasmon–decay (TPD) instability
- Saturation of TPD results in a broad spectrum of incoherent plasma waves localized in space
- Laser beams traversing this region scatter from the ensemble of plasma waves, producing an imaginary refractive index proportional to the energy density of the incoherent plasma waves

This newly identified absorption mechanism can modify the interplay of TPD, cross-beam energy transfer, and irradiation uniformity in direct-drive inertial confinement fusion (ICF).

Collaborators

D. Turnbull, R. K. Follett, D. H. Edgell,
J. G. Shaw, H. Wen, D. H. Froula, and J. P. Palastro

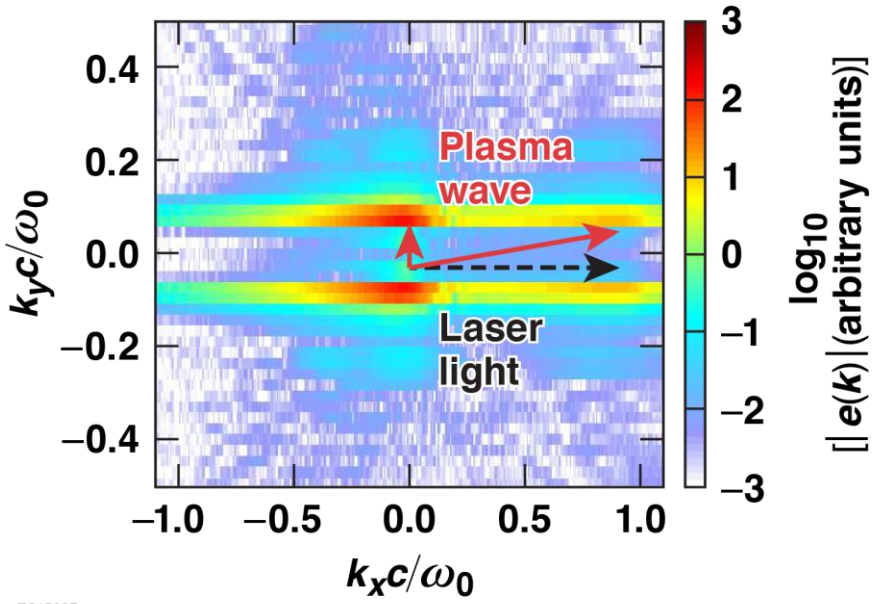
University of Rochester
Laboratory for Laser Energetics

In direct-drive ICF, the incident laser light can decay into two plasma waves near the quarter-critical surface

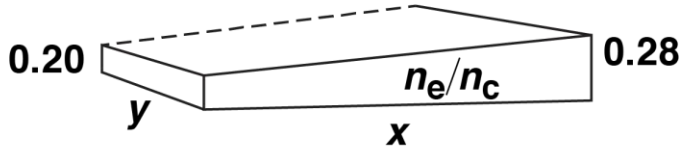
The absolute TPD instability requires:

(a) Phase matching

Plasma-wave spectrum (early stage) from LPSE* simulations



(b) Density inhomogeneity



(c) Laser intensity exceeding threshold In inhomogeneous plasmas

$$\eta^{**} = \frac{I_{14} L(\mu\mathrm{m})}{233\, T_e(\mathrm{keV})} > 1$$

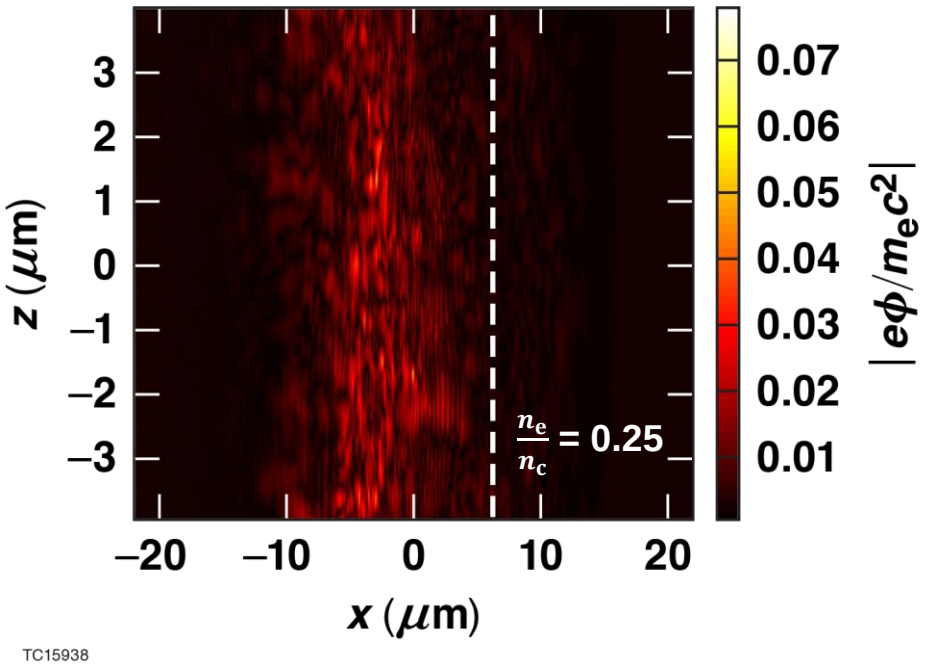
In ICF experiments on OMEGA, the threshold for instability is well exceeded.

* J. F. Myatt *et al.*, Phys. Plasmas 24, 056308 (2017).
** A. Simon *et al.*, Phys. Fluids 26, 3107 (1983).

In the saturated state, TPD results in a broad spectrum of spatially localized, large-amplitude electron plasma waves

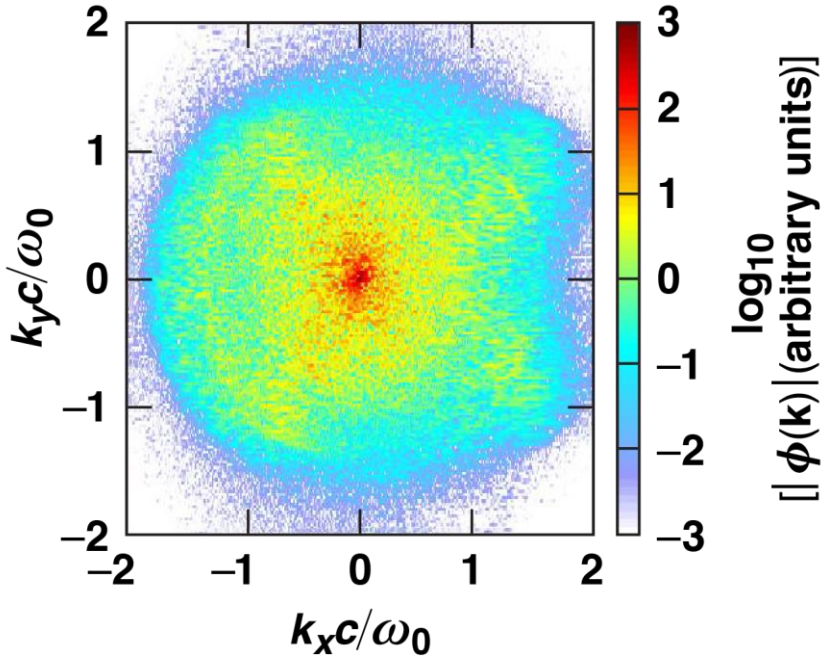
Laser beam
$I_{14} = 5$

Plasma-wave potential



TC15938

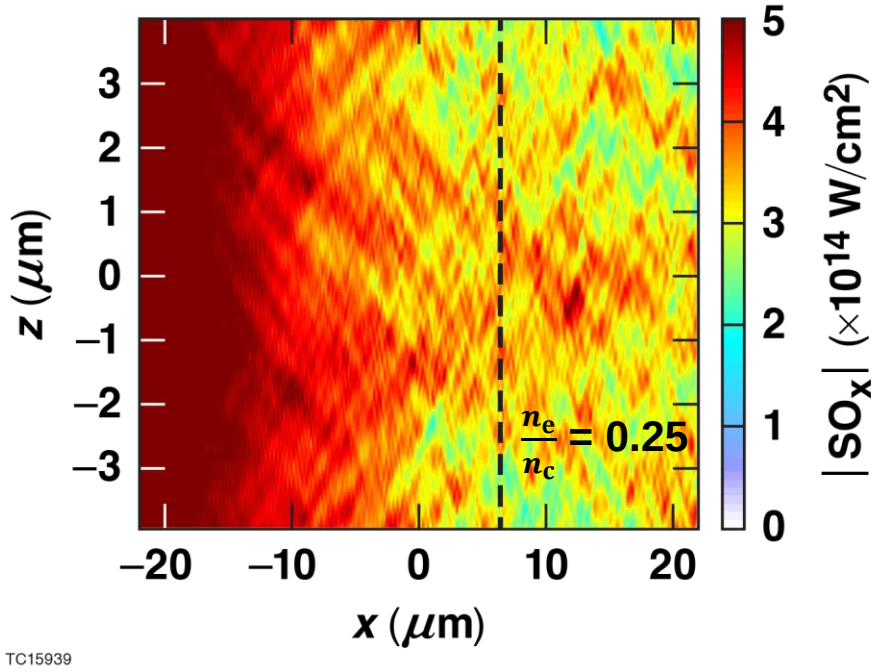
Plasma-wave spectrum



T_e = 2.5 keV; L_n = 150 μm; T_i = 1.25 keV; CH

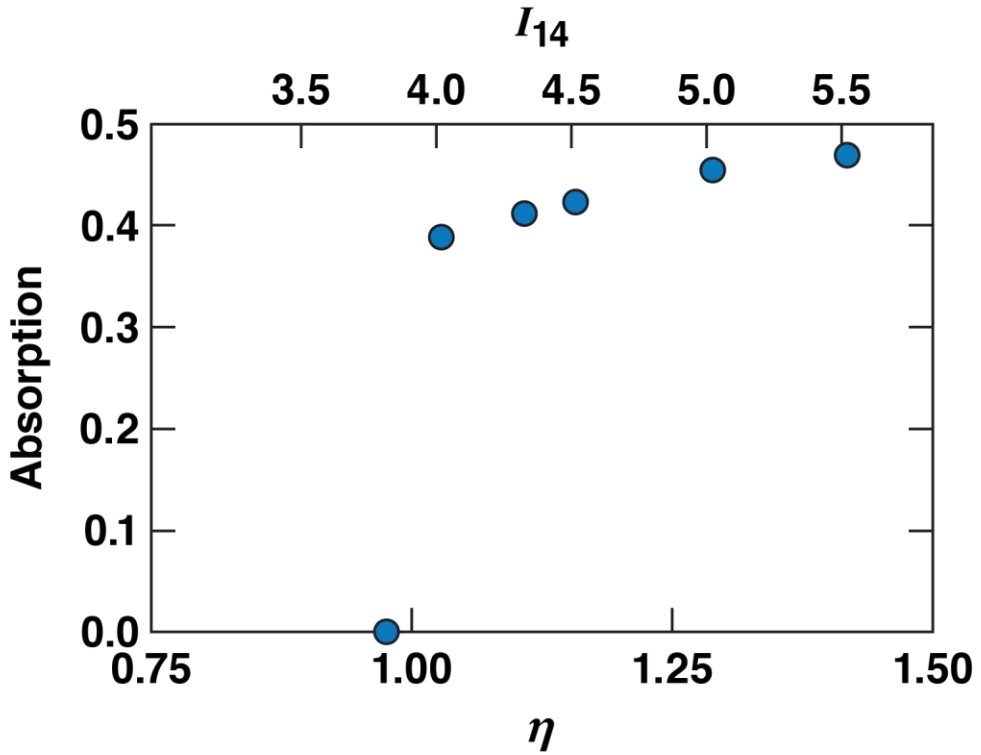
A single beam above the TPD threshold is nonlinearly absorbed as it traverses the quarter-critical region

Laser Poynting flux



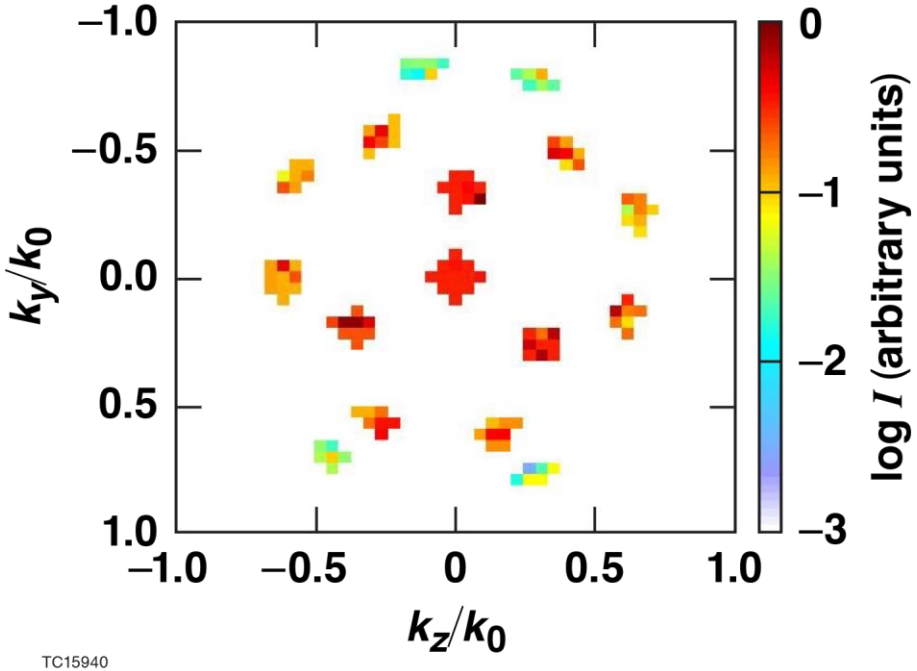
TC15939

Absorption

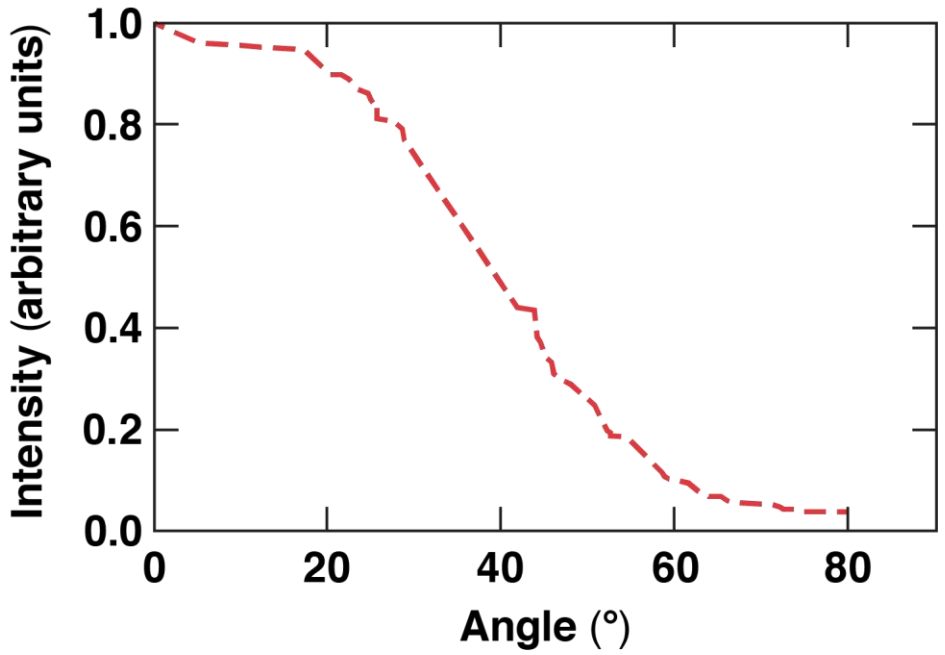


In an ICF implosion on OMEGA, an ensemble of beams with varying intensity and incidence angles overlap in the corona

Intensity of driving beams (in the plane of wave vectors perpendicular to the target normal)



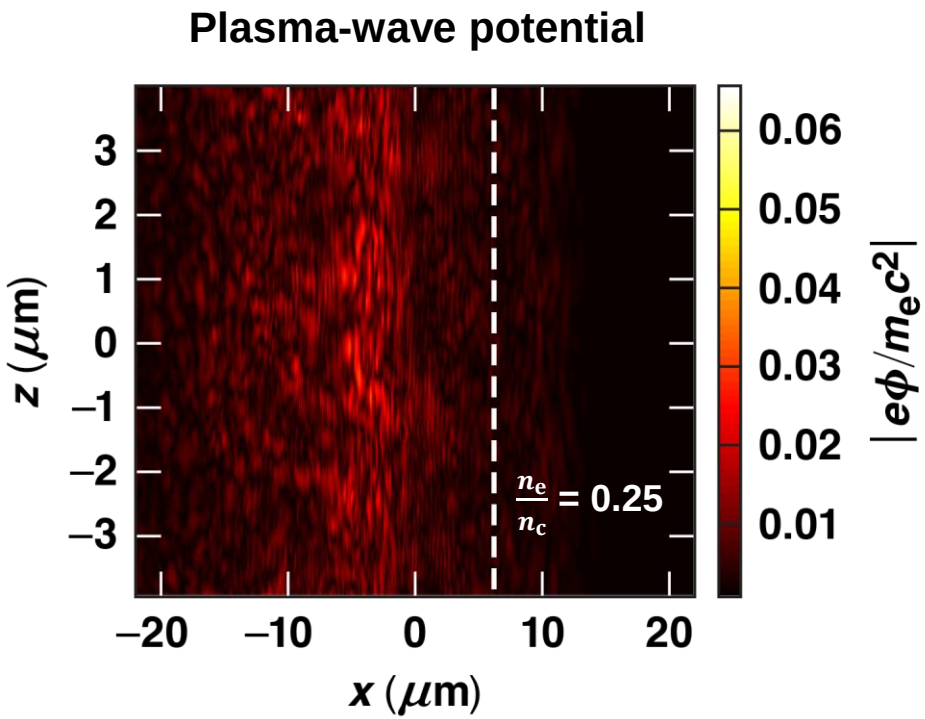
Angular dependence of beam intensities

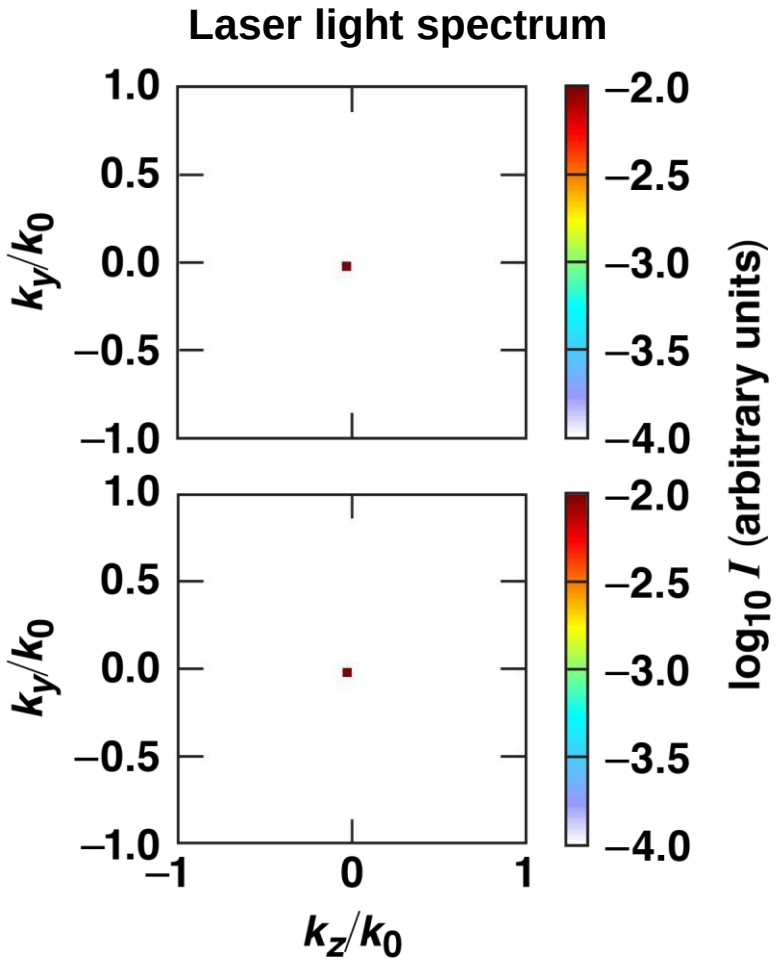


Electron plasma waves driven by higher-intensity beams can affect the lower-intensity beams and modify beam power balance.

A low-intensity probe beam traversing the ensemble of plasma waves maintains its direction and divergence

Main laser beam
$I_{14} = 5$





Before plasma-wave region

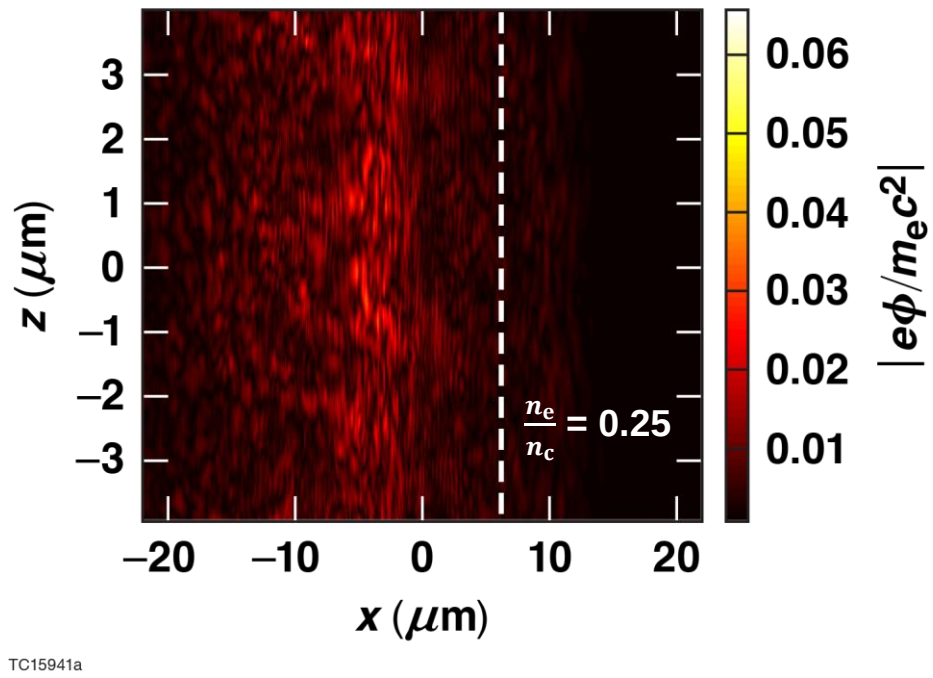
After plasma-wave region

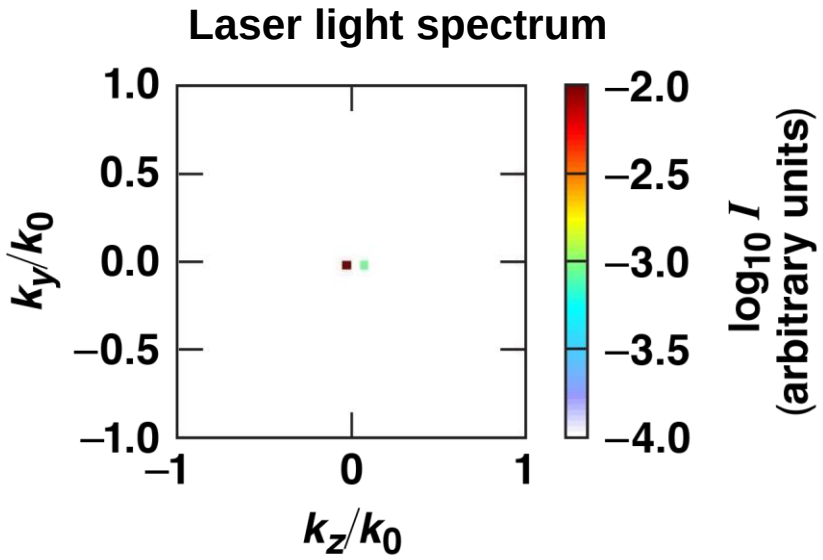
TC15941

A low-intensity probe beam traversing the ensemble of plasma waves maintains its direction and divergence

Main laser beam
I_{14} = 5

Probe laser beam
I_{14} = 0.45



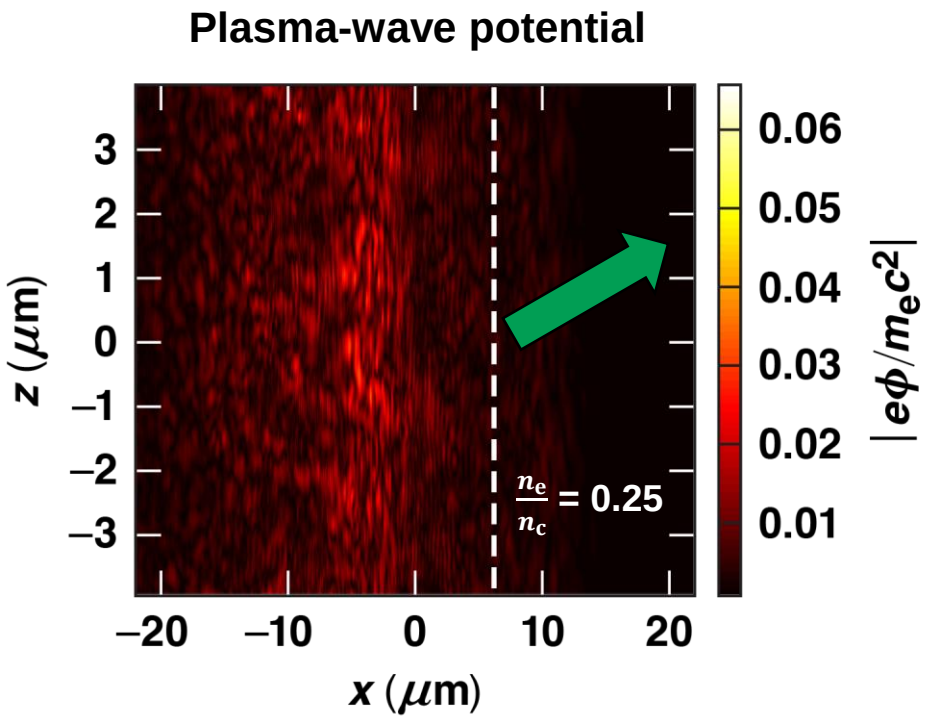


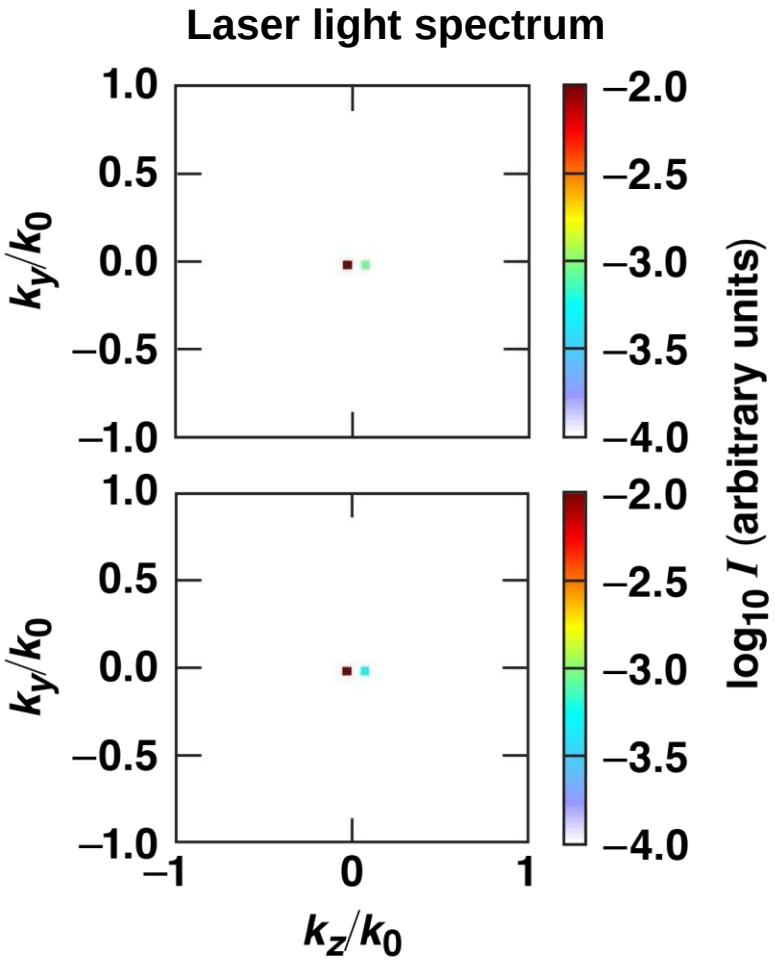
Before plasma-wave region

A low-intensity probe beam traversing the ensemble of plasma waves maintains its direction and divergence

Main laser beam
I_{14} = 5

Probe laser beam
I_{14} = 0.45





Before plasma-wave region

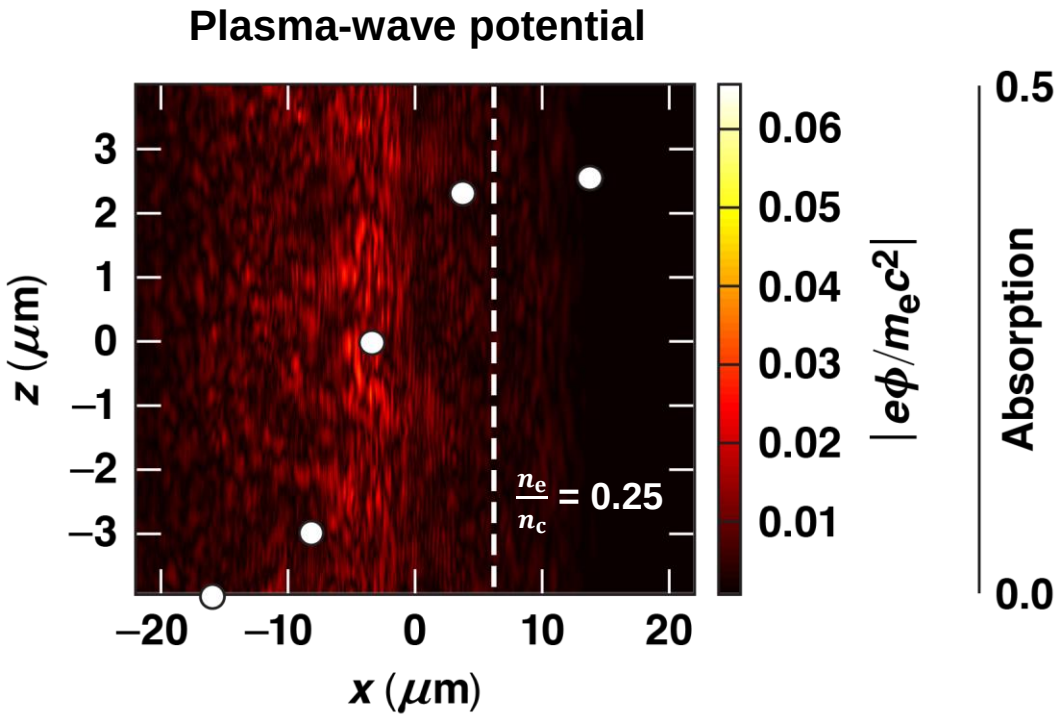
After plasma-wave region

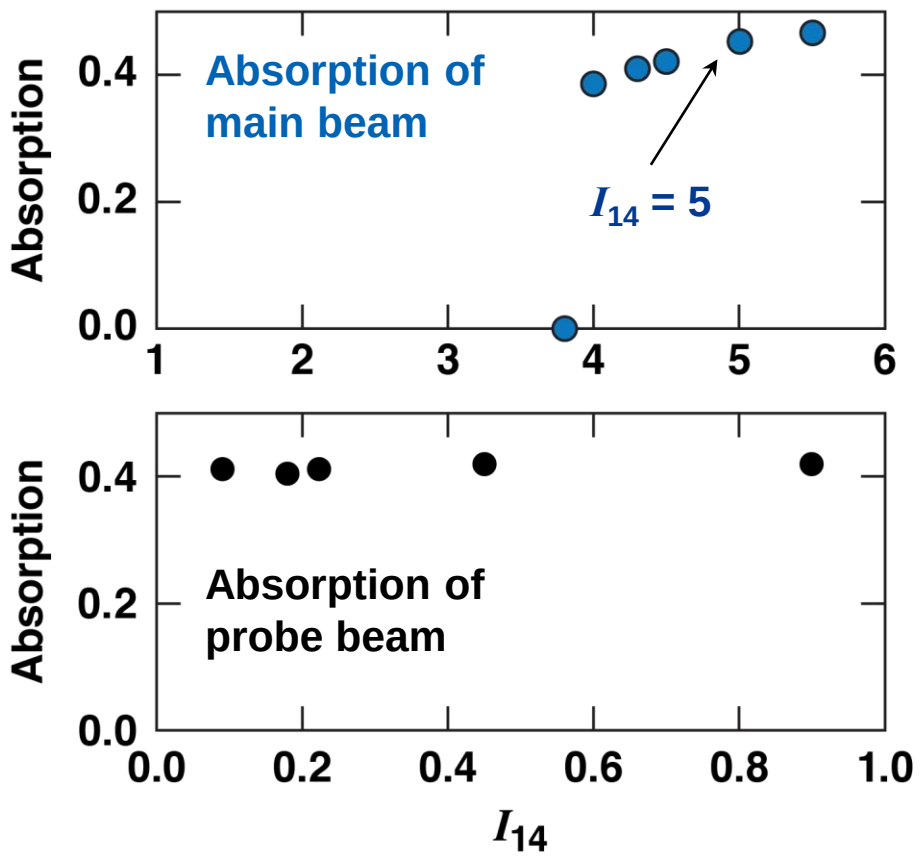
TC15941b

Even though the probe beam is below threshold, it is absorbed as it passes through the instability region

Main laser beam
I_{14} = 5

Probe laser beam
I_{14} = 0.45





TC15941c

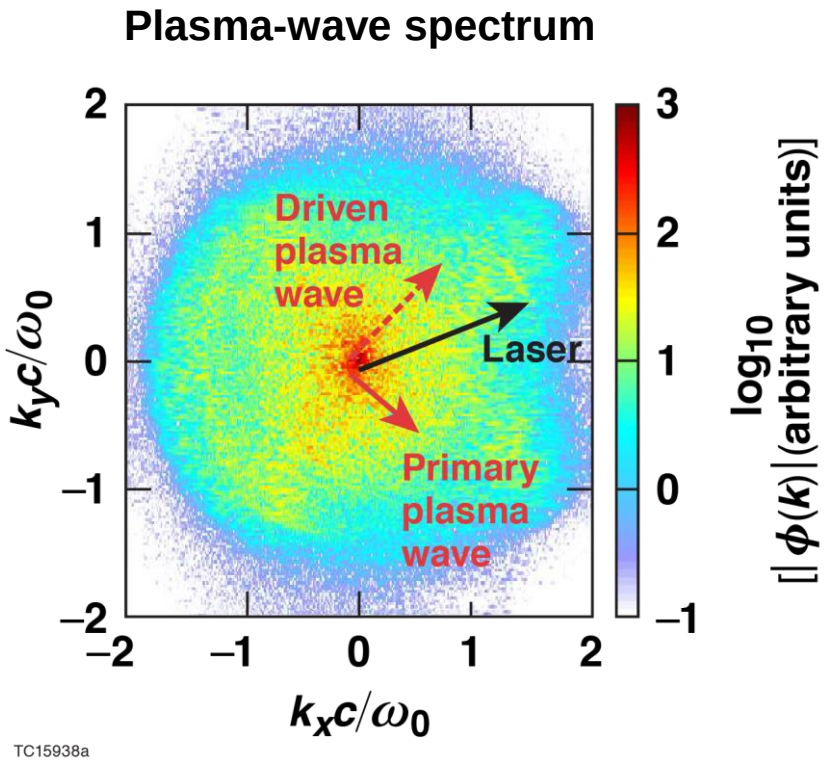
The absorption of the probe beam is independent of its intensity.

The linear absorption of probe beam is due to an imaginary refractive index formed by incoherent ensemble of plasma waves

- Plasma waves interact with probe beam $\vec{E}_0$ in TPD
  - for a set of incoherent primary plasma waves: $\vec{E}_{\mathrm{p}} = \sum_j \vec{E}_{\mathrm{pj}}\, e^{\left(i\vec{k}_{pj}\cdot\vec{\mathrm{r}} - i\omega_{\mathrm{pj}}t\right)}$
  - a set of driven plasma waves is generated: $\omega_{\mathrm{sj}} = \omega_0 - \omega_{\mathrm{pj}}\ ;\ \vec{k}_{sj} = \vec{k}_0 - \vec{k}_{pj}$
- After substituting the driven plasma wave into the nonlinear current in the equation for laser light, the imaginary refractive index is obtained

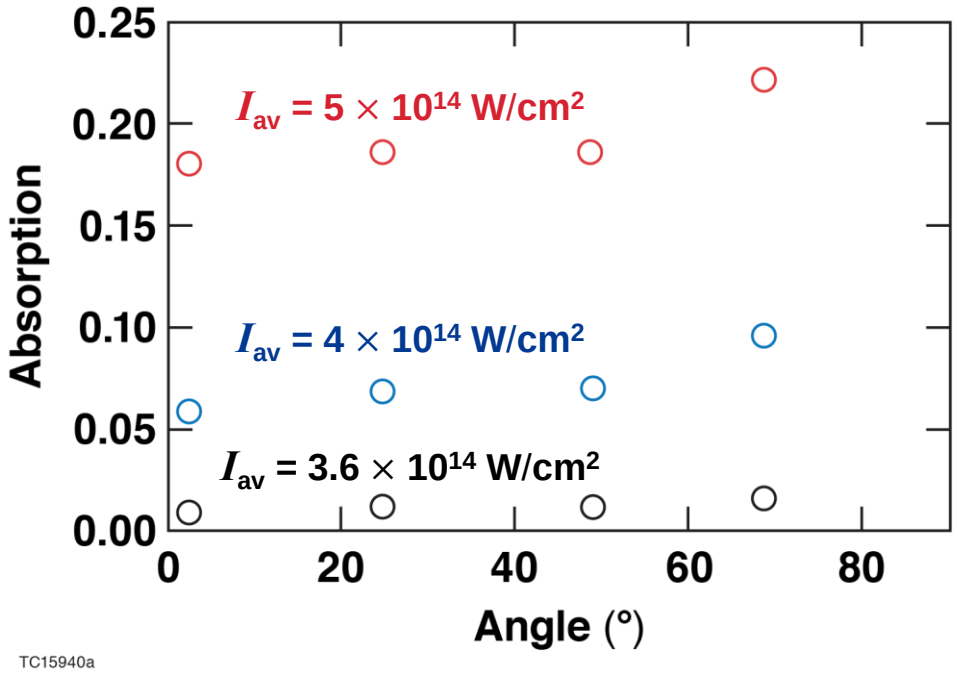
$$\varepsilon = \mathrm{i}\frac{e^2}{4m_e^2\omega_0^3}\sum_j \frac{\left|\vec{k}_{\mathrm{pj}}\cdot\vec{E}_{\mathrm{pj}}\right|^2}{\left[\gamma_{sj} - \mathrm{i}(\omega_{sj}^2 - \omega_p^2(\vec{r}) - 3\vec{k}_{sj}^2V_{Te}^2)/2\omega_{\mathrm{sj}}\right]}$$

- where the denominator is determined by plasma wave resonance



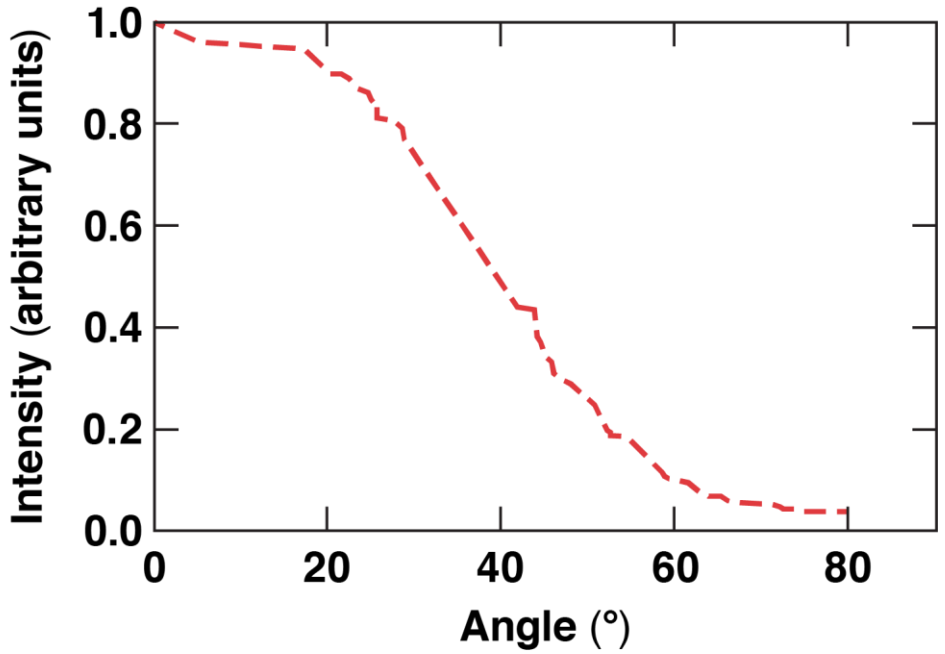
Any probe beam undergoes linear absorption.

For all incident OMEGA beams, the scaling of absorption with beam incidence angle has been obtained



Absorption is averaged over angular range

Angular dependence of beam intensities



Absorption as a function of incidence angle is close to constant.

Summary/Conclusions

An ensemble of incoherent plasma waves enhances the linear absorption of laser light through the region near quarter-critical density

- Near quarter-critical density in a plasma, an incident laser photon can decay into two plasmons, driving the two-plasmon–decay (TPD) instability
- Saturation of TPD results in a broad spectrum of incoherent plasma waves localized in space
- Laser beams traversing this region scatter from the ensemble of plasma waves, producing an imaginary refractive index proportional to the energy density of the incoherent plasma waves

This newly identified absorption mechanism can modify the interplay of TPD, cross-beam energy transfer, and irradiation uniformity in direct-drive ICF.