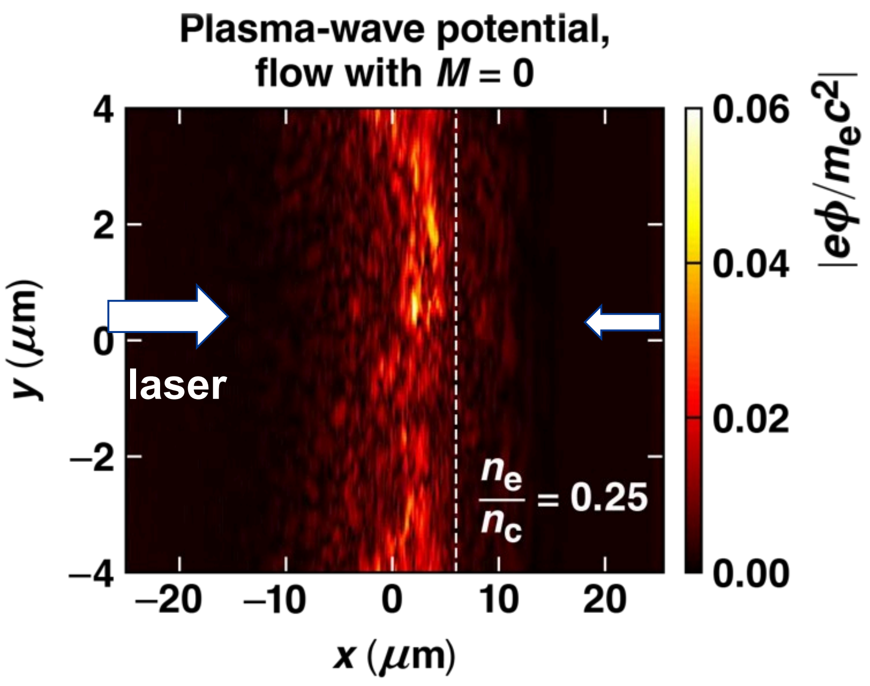
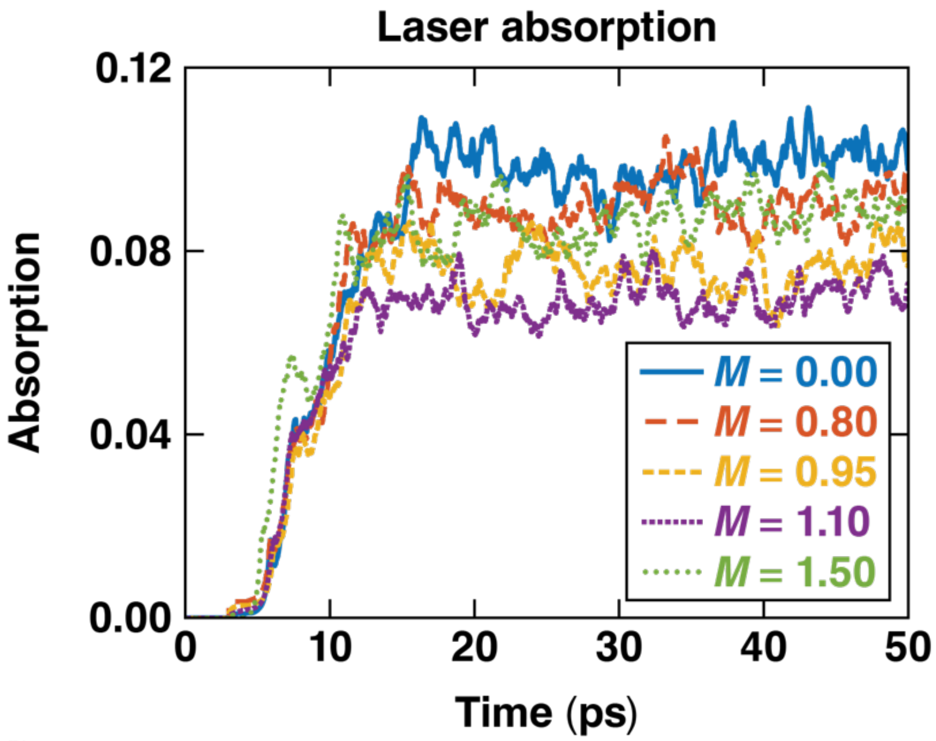
Effect of Flow on Laser–Plasma Interactions near the Quarter-Critical Density in the Plasmas of Inertial Confinement Fusion



$I_{av} = 4.8 \times 10^{14}$ W/cm^2

TC16147a

Flow
(Mach number M)
Is changed



TC16148a

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

64th Annual Meeting of the American Physical Society
Division of Plasma Physics
Spokane WA, 17-21 October 2022

Summary

In the modeling of direct-drive inertial confinement fusion plasmas, the reduction of two-plasmon decay instability and of the laser absorption due to plasma flow is observed

- Two LPI processes: crossed-beam energy transfer (CBET) and two-plasmon decay (TPD) have a large influence on the coupling of laser power to plasmas, and these two processes coexist in the plasma region near the quarter-critical density.

- Three-dimensional modeling using the LPSE platform has confirmed that plasma flow can limit the growth of TPD and increase CBET for the conditions relevant to the experiments on the OMEGA Laser System.

- At the optimum magnitude of plasma flow close to Mach-1 the intensity of plasma waves and the laser absorption is decreased by about one third compared to no flow case.

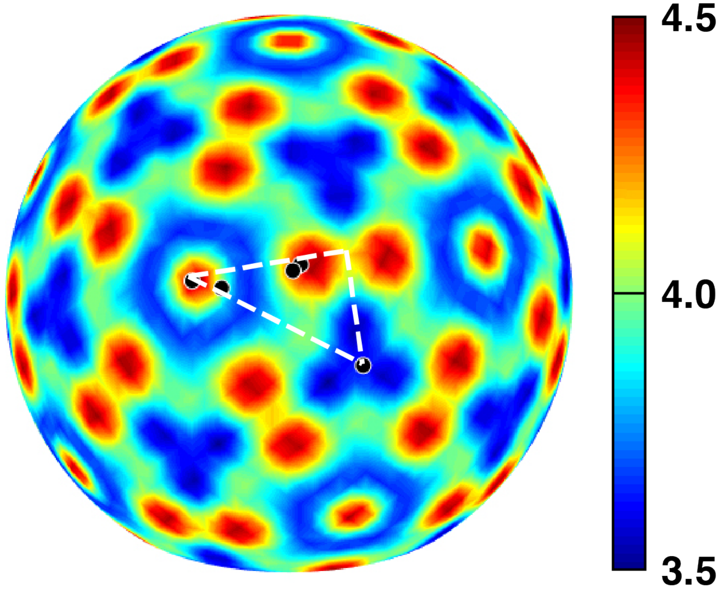
Collaborators

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

University of Rochester
Laboratory for Laser Energetics

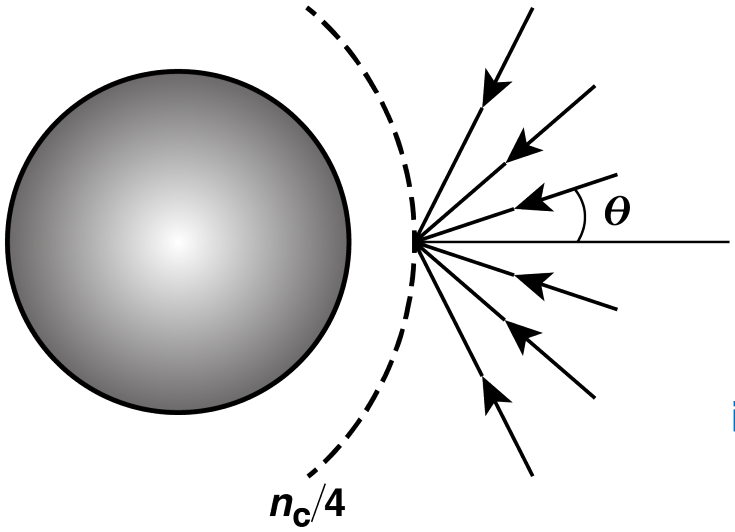
Laser–plasma interaction has been modeled in OMEGA plasmas near the quarter-critical density where the laser intensity profile is produced by multiple laser beams

Ray tracing of
60 overlapping beams



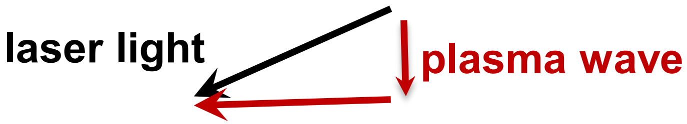
$I_{av} = 4 \times 10^{14}$ W/cm^2

TC15593b

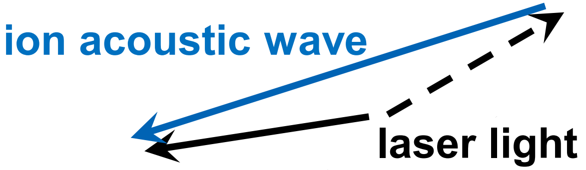


2 LPI processes:

Two-plasmon decay (TPD)*



Crossed-beam
energy transfer (CBET)**



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

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

Computational platform *LPSE* can model nonlinear LPI, including TPD and CBET

- The model describes the evolution of laser light (enveloped near frequency ω_0), plasma-wave field (near ω_p), and ion-acoustic perturbation δN

Laser light
$$i\frac{\partial \mathrm{v}_0}{\partial t} + i\gamma_0 \circ \mathrm{v}_0 + \frac{c^2}{2\omega_0}\nabla^2 \mathrm{v}_0 + \frac{\omega_0^2 - \omega_p^2\left(1 + N_0 + \delta N\right)}{2\omega_0}\mathrm{v}_0 = \frac{i\omega_p}{4\omega_0}\left[\left(\nabla \cdot \mathrm{v}_p\right)\mathrm{v}_p\right]_T \cdot e^{-i\delta\omega t}$$

Plasma wave
$$i\frac{\partial \mathrm{v}_p}{\partial t} + i\gamma_p \circ \mathrm{v}_p + \frac{3v_{Te}^2 c^2}{2\omega_1}\nabla^2 \mathrm{v}_p + \frac{\omega_p\left(1 + N_0 + \delta N\right)}{2}v_p = \frac{1}{\omega_p}\left[\nabla\left(v_p^* \cdot v_0\right) - \left(\nabla \cdot \mathrm{v}_p^*\right)\mathrm{v}_0\right] \cdot e^{i\delta\omega t}$$

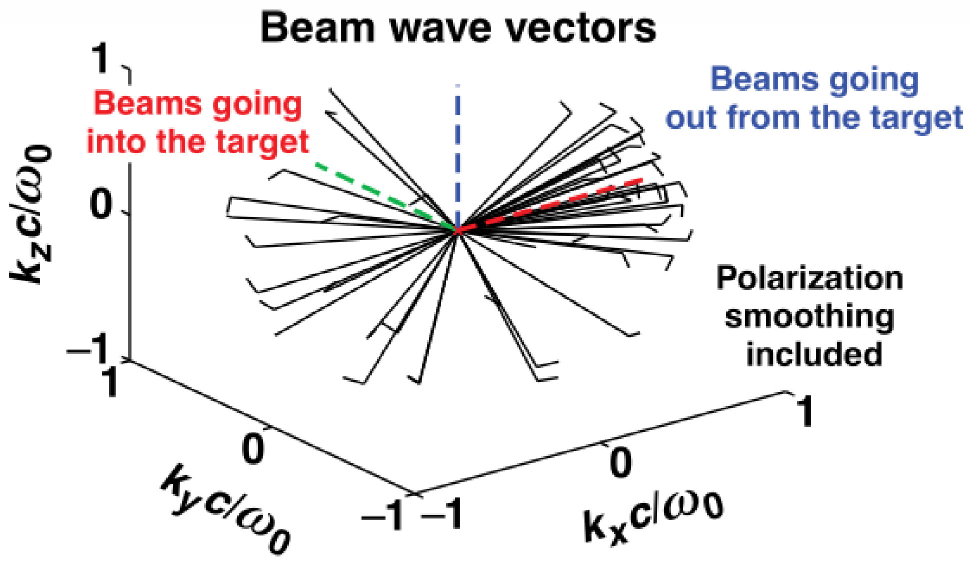
Ion acoustic
$$\frac{\partial^2 \delta N}{\partial \tau^2} + 2\gamma_{ia} \times \frac{\partial \delta N}{\partial \tau} - \frac{c^2}{2\omega_0} c_s^2 \nabla^2 \delta N = \frac{1}{16\pi n_0 m_i}\nabla^2\left[\left|E_p\right|^2 + \frac{n_0}{n_c}\left|E_0\right|^2\right]$$

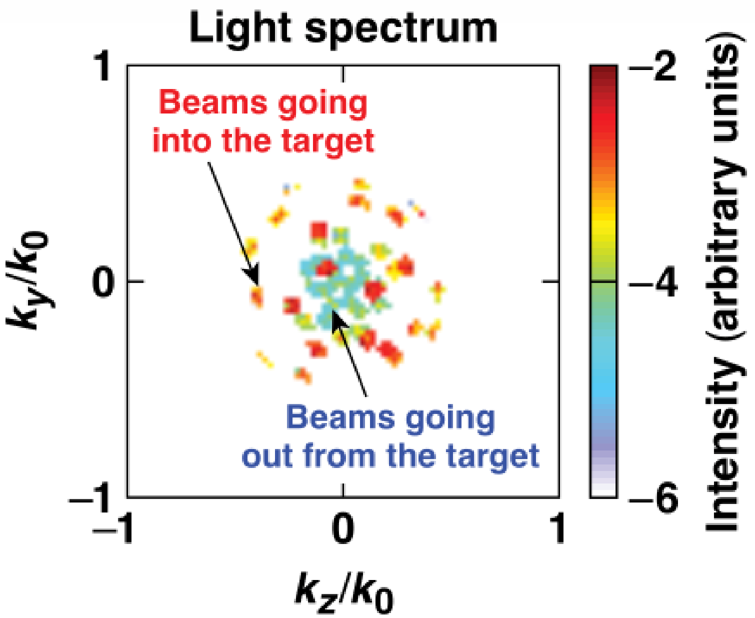
where $\mathrm{V}_j = \frac{ieE_j}{m_e\omega_j}(j = 0, \mathrm{p})\frac{\partial}{\partial\tau} = \frac{\partial}{\partial t} + \mathrm{U}_0 \times \nabla,$

U_0: flow; N_0: background density profile; $\delta\omega = \omega_0 - 2\omega_\mathrm{p}$: frequency mismatch

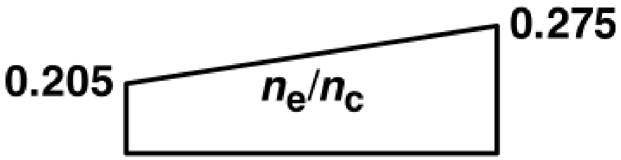
It is possible to study the relative importance of different wave-coupling processes.

Modeling included all OMEGA laser beams – going into the target and also going out from the target





Plasma parameters



L_n = 170 μm, T_e = 2.5 keV, T_i = 1.25 keV; CH

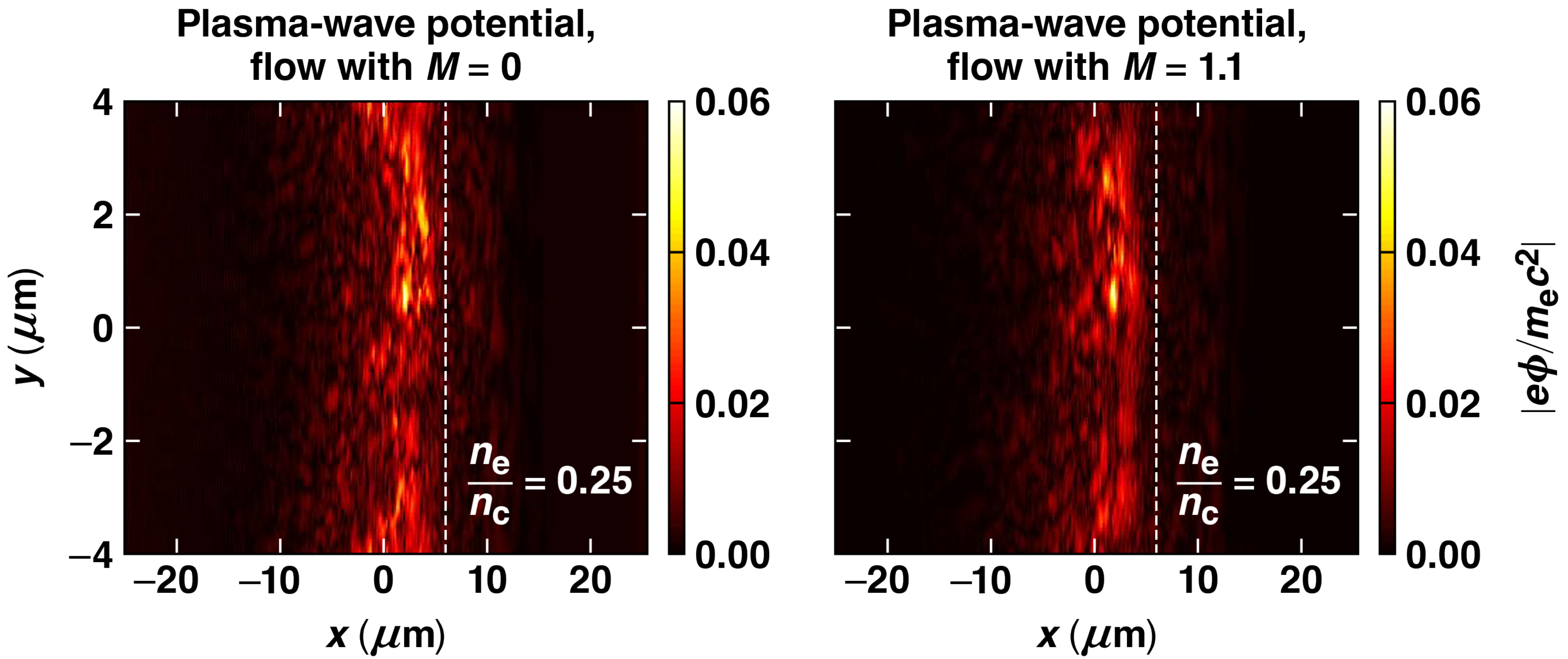
TPD threshold parameter

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

---

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

Simulations with LPSE found that the intensity of plasma waves in nonlinear TPD depends on the flow velocity



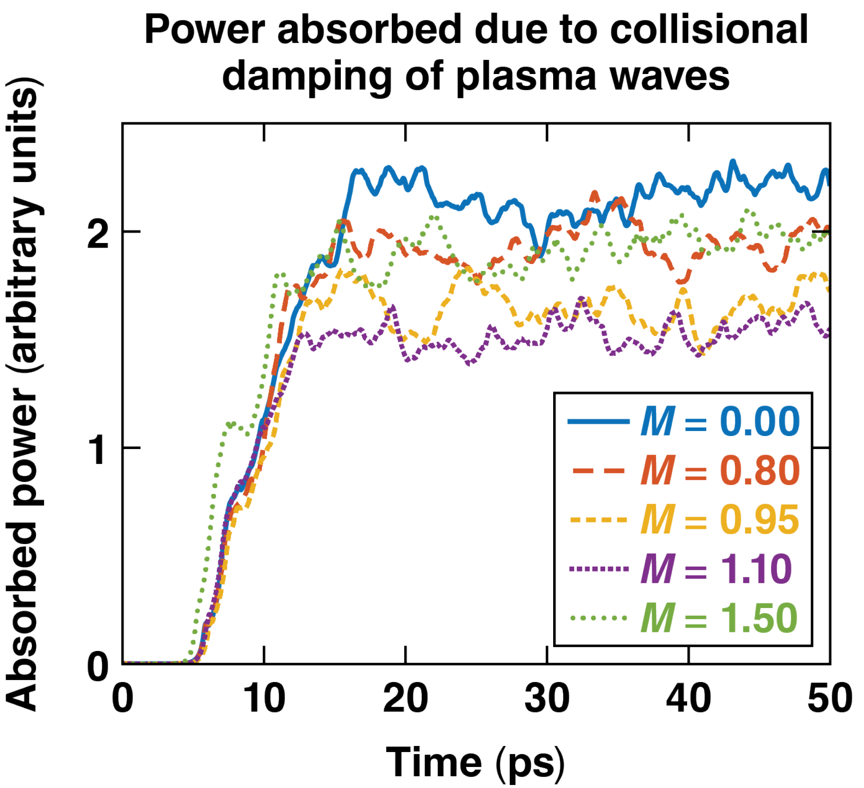
I_{av} = 4.8 × 10^{14} W/cm^2

η = 1.4

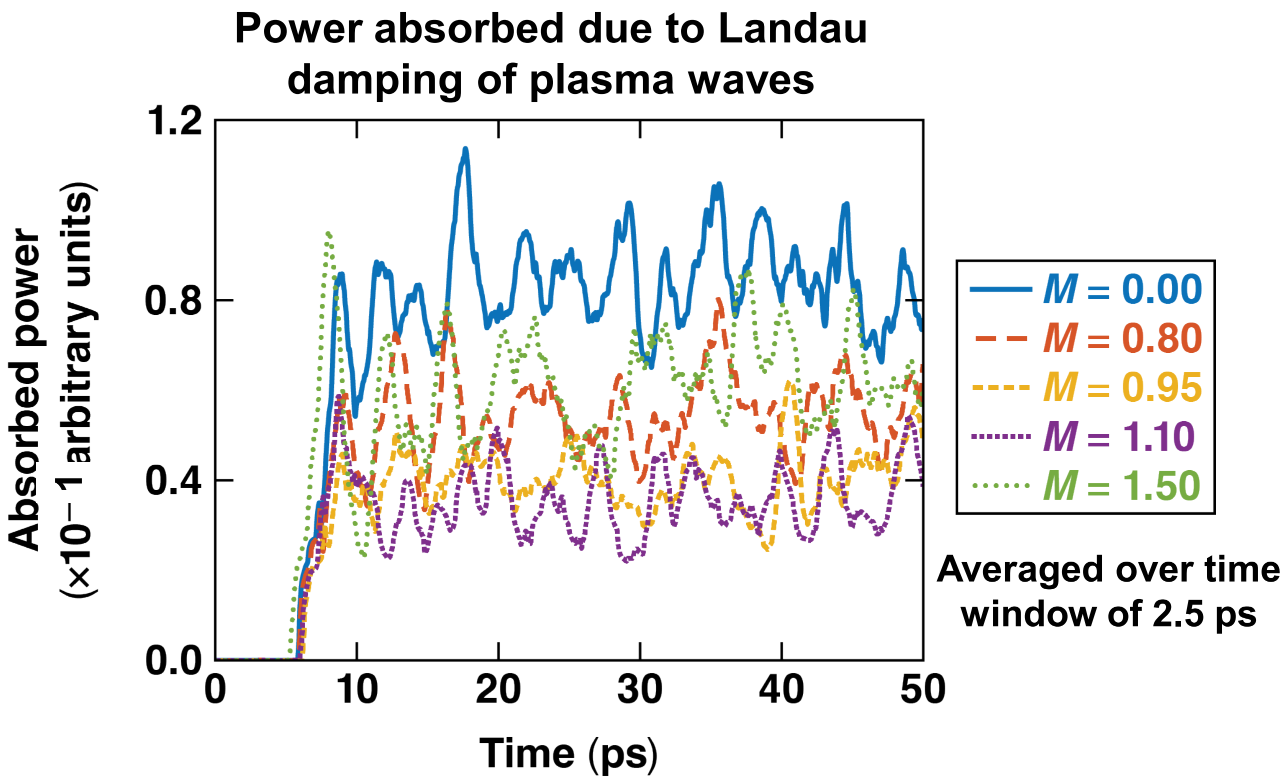
TC16147a

The instability region is clearly localized near the quarter-critical density, It is more narrow for M=1.1 than for M=0

Two mechanisms for the coupling of laser energy to plasma are the collisional damping and the Landau damping of plasma waves



TC16149a



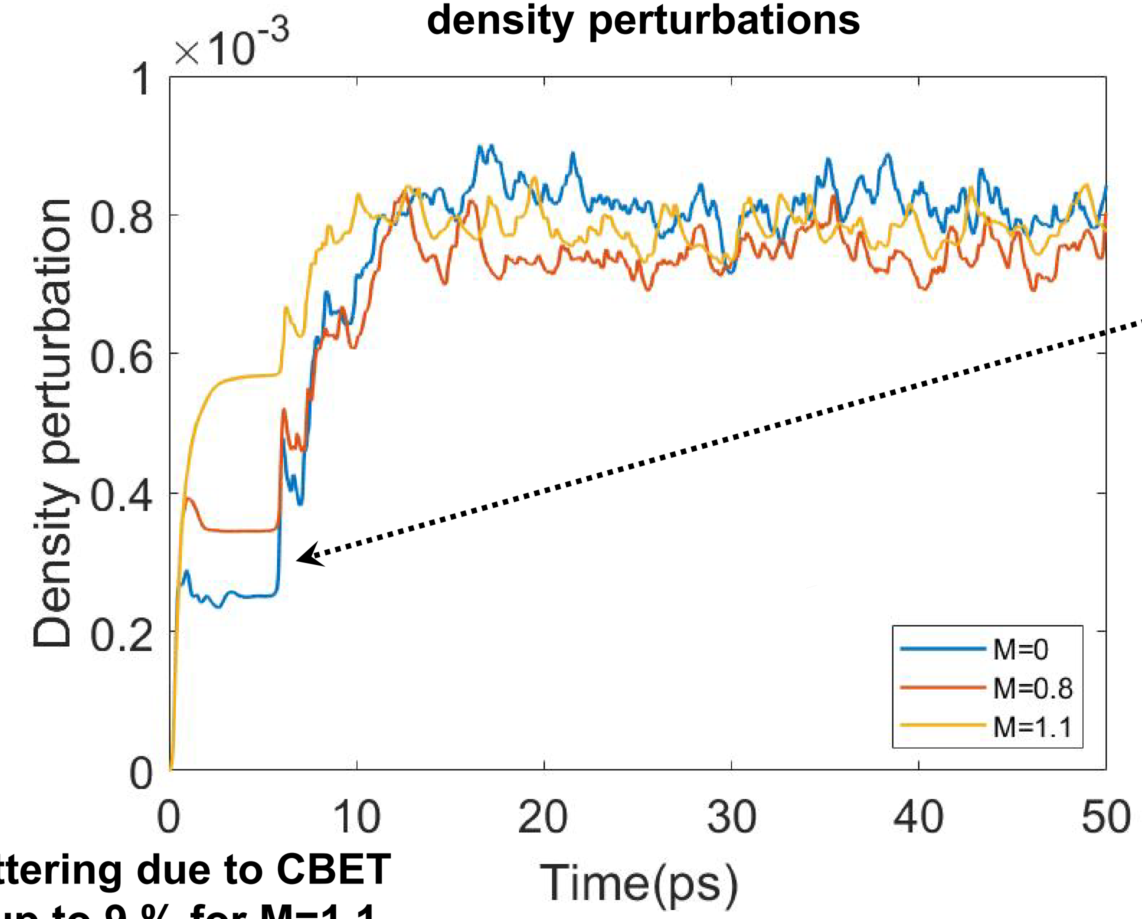
TC16229

Nonlinear saturation is reached at 10-20 ps

The nonlinear saturation of plasma waves depends on the flow magnitude.

The growth of CBET and TPD can be characterized by the magnitude of low-frequency density perturbations involved in CBET and in saturation of TPD

Averaged low-frequency density perturbations

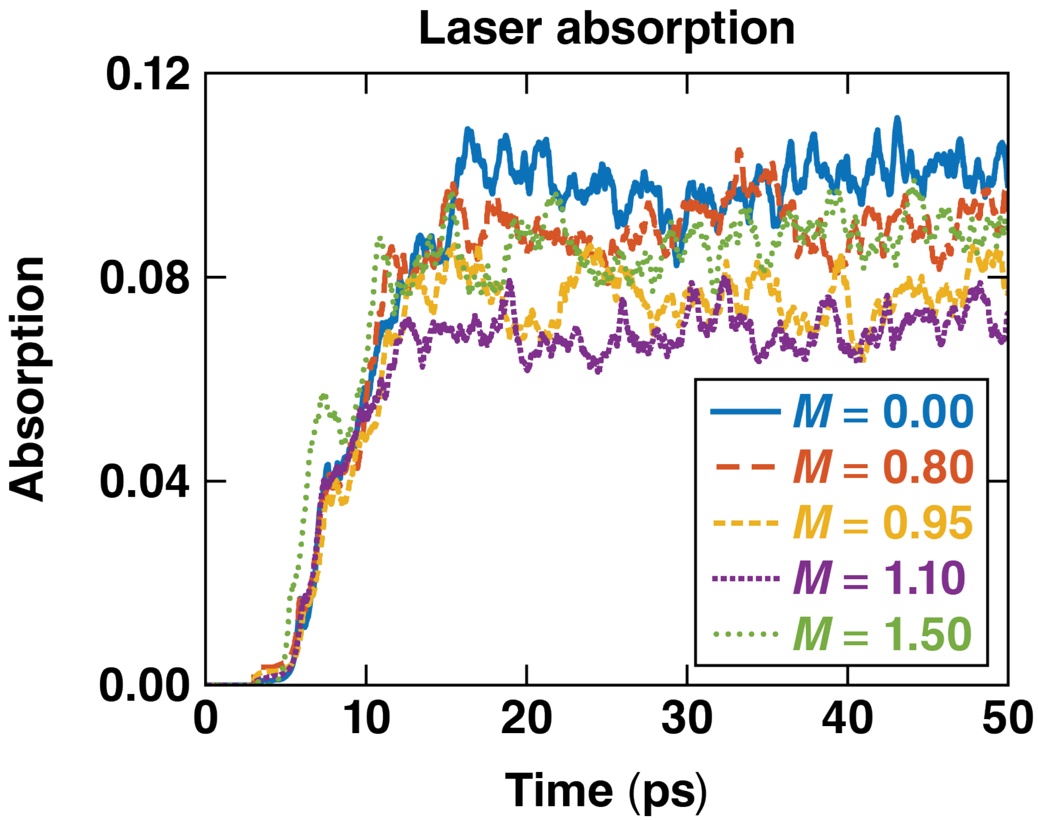


Scattering due to CBET is up to 9 % for M=1.1

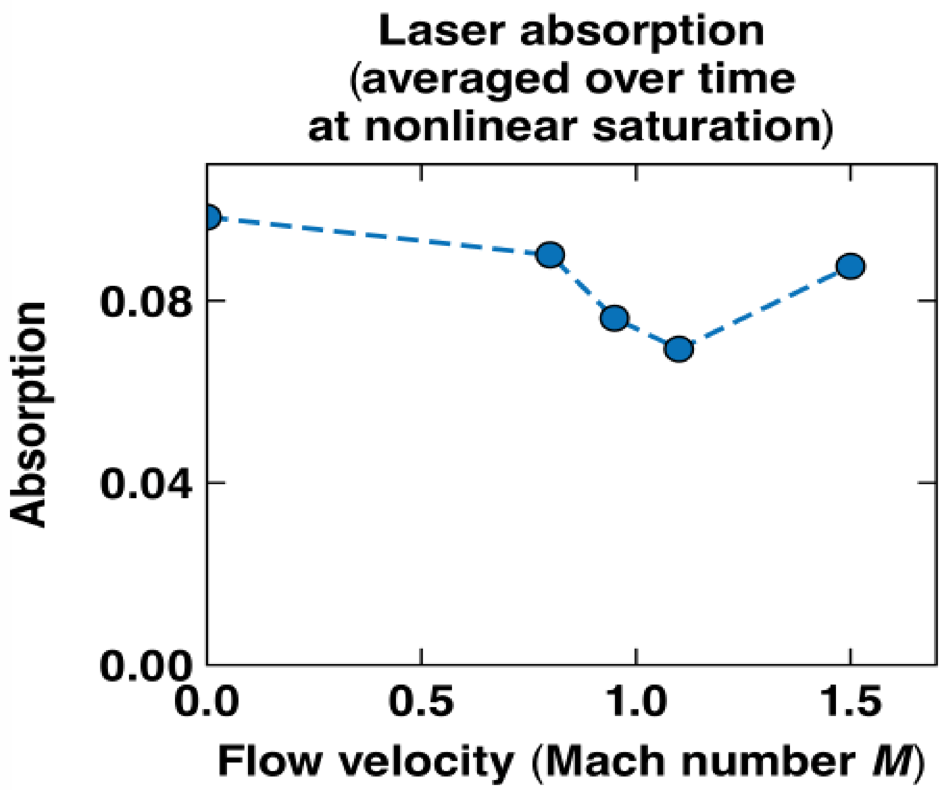
(1) At times up to 10 ps CBET can develop, and the magnitude of density perturbations strongly depends on the flow

(2) At times after 10-20 ps TPD develops, and the magnitude of density perturbations reaches saturation

The laser absorption in the region near quarter-critical density is a result of both TPD and CBET, and depends on the flow velocity



TC16148a



The largest reduction of laser absorption is found at when flow velocity is close to Mach 1.

Conclusions

In the modeling of direct-drive inertial confinement fusion plasmas, the reduction of two-plasmon decay instability and of the laser absorption due to plasma flow is observed

UR LLE
UNIVERSITY of ROCHESTER

- Two LPI processes: crossed-beam energy transfer (CBET) and two-plasmon decay (TPD) have a large influence on the coupling of laser power to plasmas, and these two processes coexist in the plasma region near the quarter-critical density.

- Three-dimensional modeling using the LPSE platform has confirmed that plasma flow can limit the growth of TPD and increase CBET for the conditions relevant to the experiments on the OMEGA Laser System.

- At the optimum magnitude of plasma flow close to Mach-1 the intensity of plasma waves and the laser absorption is decreased by about one third compared to no flow case.