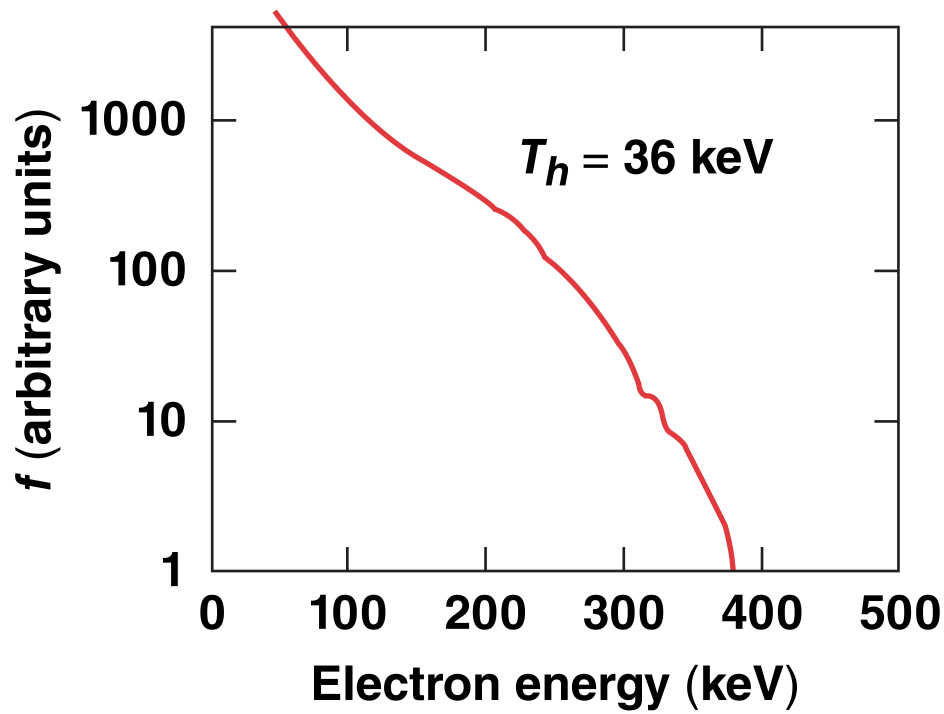
Modeling Two-Plasmon-Decay Instability in Direct-Drive Inertial Confinement Fusion



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Summary

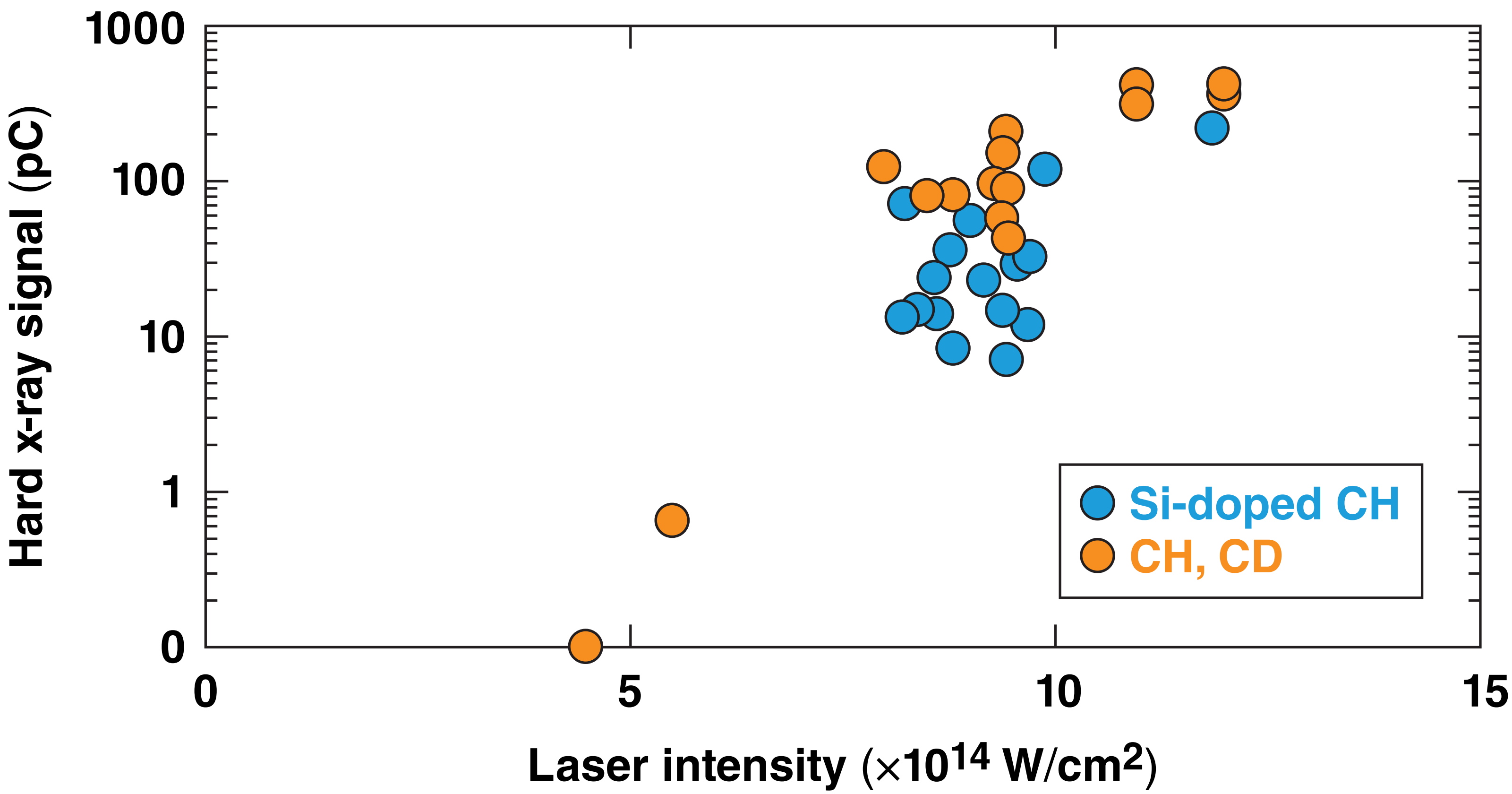
The saturation of two-plasmon-decay instability is caused by the broad spectrum of low-frequency density perturbations

- In the linear stage of two-plasmon-decay instability (TPD), the convective and absolute growth produces a broad angular spectrum of primary Langmuir waves
- In the saturation stage of TPD, a broad spectrum of low-frequency density perturbations is generated, including the perturbations at the onset of the Langmuir decay instability
- The temperature of the fast electrons, produced in TPD, is defined by the spectrum of Langmuir waves, including the Landau cutoff

Outline

- The threshold of TPD for OMEGA parameters
- The linear stage of TPD growth: absolute and convective
- The properties of the fast electrons, generated in TPD
- The saturation of TPD

In OMEGA experiments, the hard x-ray production depends on ion composition



TC8036d

The TPD instability threshold is influenced by the interplay of plasma inhomogeneity, wave damping, and resonance detuning caused by beam incoherence

UR LLE

- **Plasma-wave damping**

$$\left(\frac{\gamma_e}{\omega_{p0}}\right)_{coll} = 0.5 \times 10^{-3} \frac{(Z/5.3)}{(T_e/2\,\text{keV})^{3/2}}$$

- **Detuning due to inhomogeneity**

$$\frac{1}{2\,k_0 L} = \frac{2.1 \times 10^{-4}}{(L/150\,\mu m)}$$

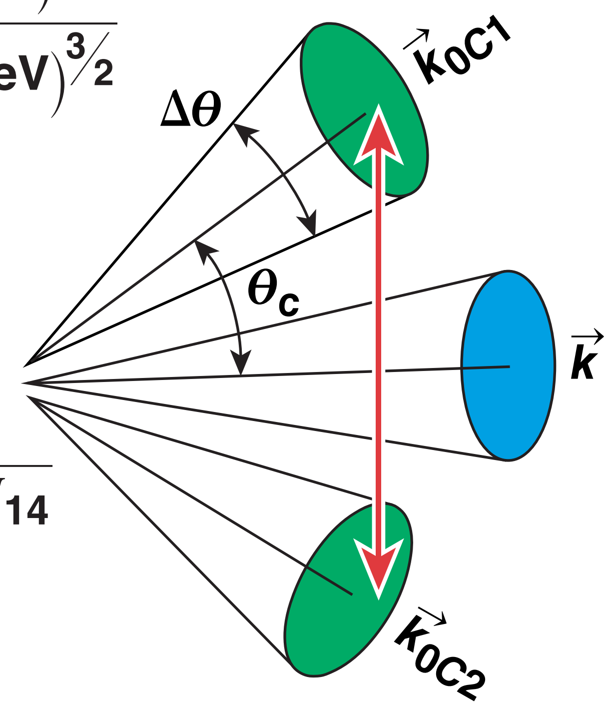
- **Homogeneous 3-wave growth rate**

$$\gamma^0 = \frac{k_0 |V_{osc}|}{\omega_{p0}} = 0.26 \times 10^{-2} \sqrt{I_{14}}$$

- **Detuning due to beam incoherence**

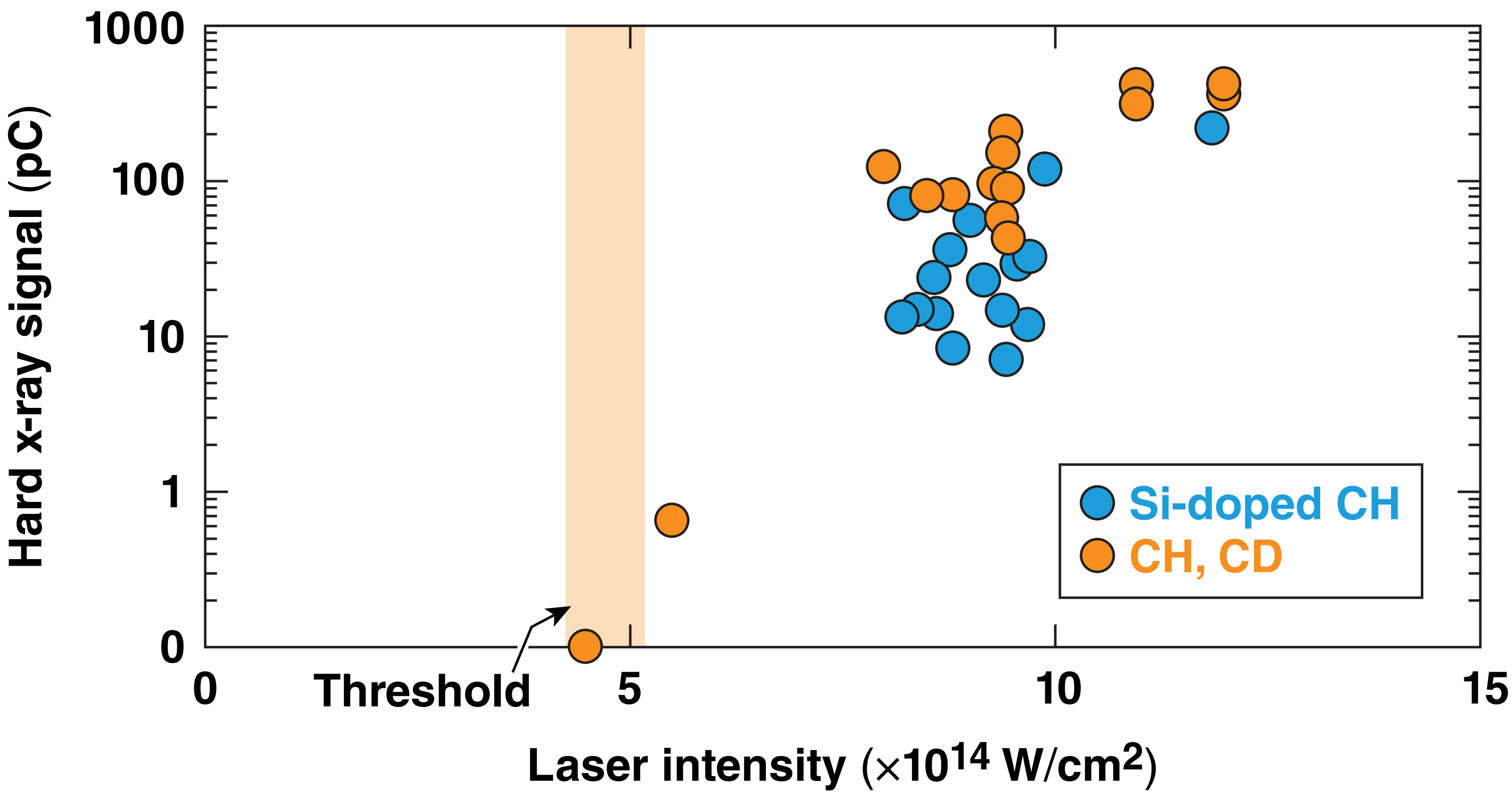
$$\frac{\Delta\omega}{\omega_{p0}} = 3\,k\,k_0 \lambda_{De}^2 |\sin\theta_c| \Delta\theta$$

$$\frac{\Delta\omega}{\omega_{p0}} = 4 \times 10^{-2} (T_e/2\,\text{keV})\, \Delta\theta \sin\theta_c$$



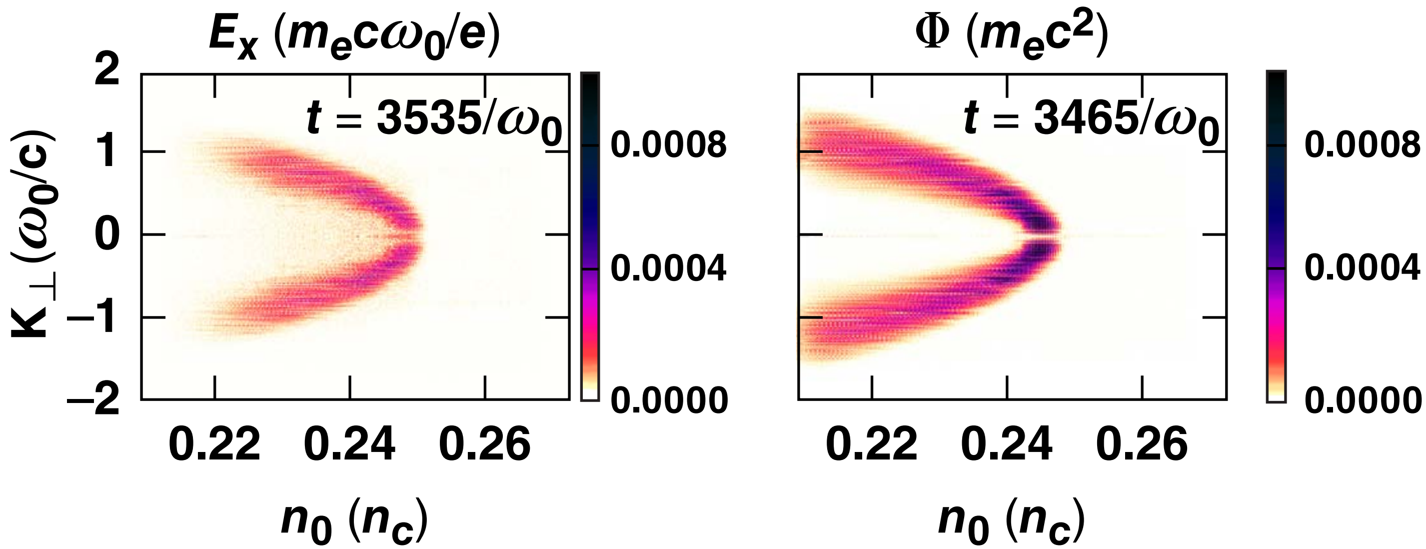
TC7846c

The calculated TPD threshold is in reasonable agreement with the hard x-ray onset intensity



TC7797d

The fastest-growing wave vectors change with the position in the homogeneous plasmas



PIC *OSIRIS* simulation

Fluid simulation

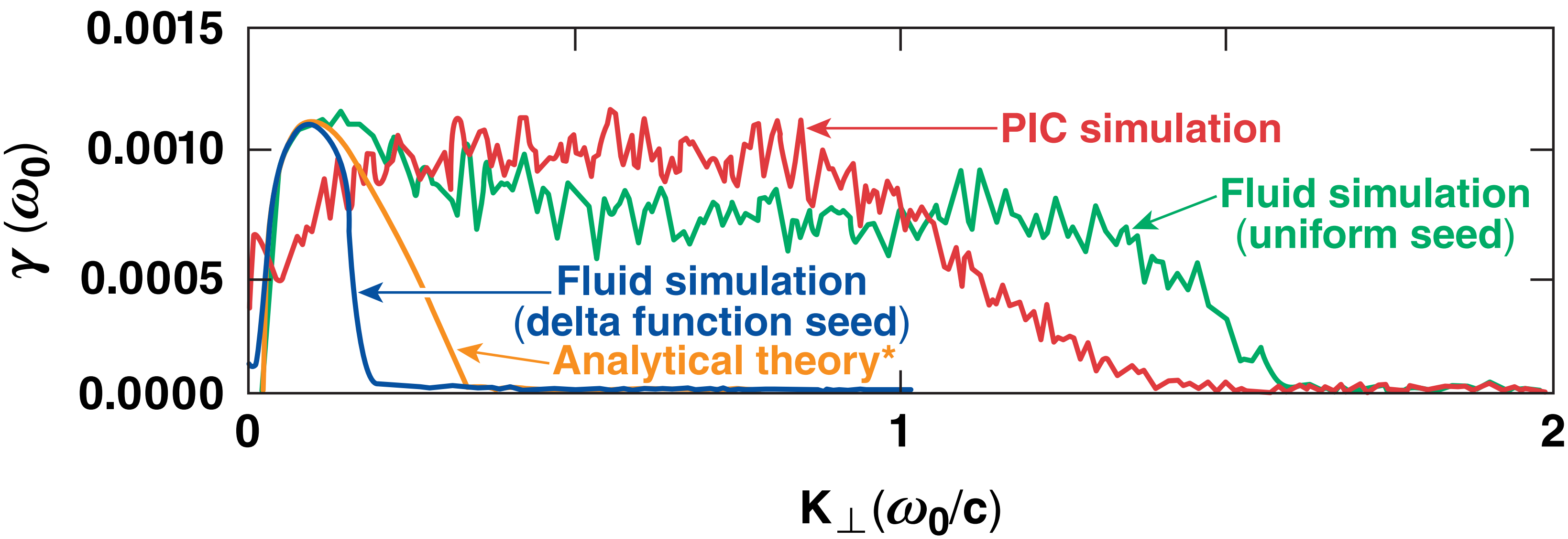
$I = 10^{15}$ W/cm^2, $T_e = 2$ keV, $L_N = 150$ μm

The longitudinal and transverse wave vectors lie on the TPD maximum-growth hyberbola.

TC8856

*R. Yan *et al.*, Phys. Rev. Lett. 103, 175002 (2009).

In the linear stage of TPD, absolute and convective growth generates a broad spectrum of Langmuir waves



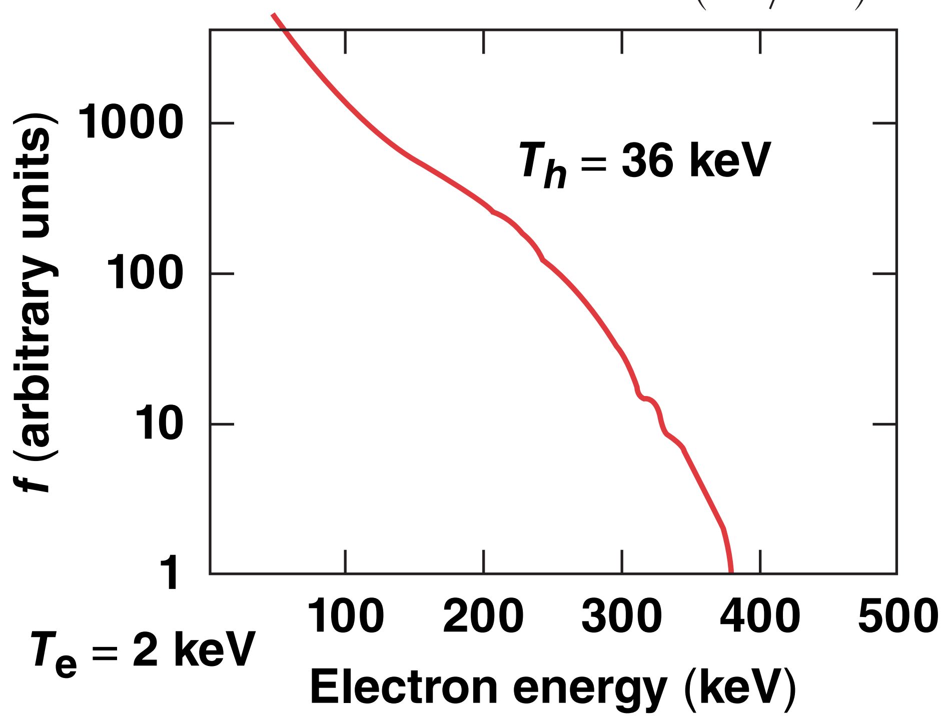
I = 10^{15} W/cm^2, T_e = 2 keV, L_N = 150 μm

TC8855

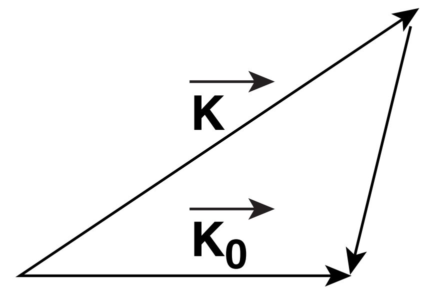
*A. Simon *et al*., Phys. Fluids 26, 3107 (1983).

The distribution of fast electrons, generated in the TPD, depends on the spectrum of the Langmuir waves

$$f(\varepsilon) \sim \sqrt{\varepsilon} \cdot \exp\left(-\varepsilon / T_h\right)$$



T_e = 2 keV



$K\lambda_{De} \approx 0.22 \; \gamma_L \approx \gamma_c$

Landau cutoff

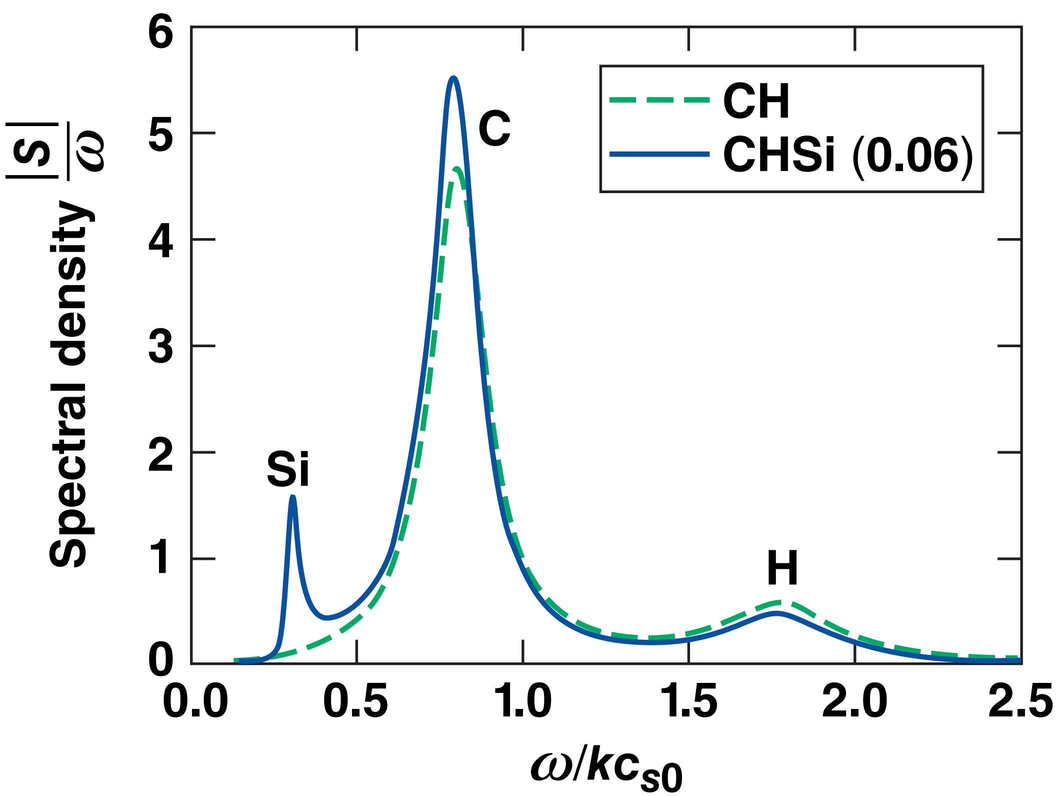
Boundary conditions:
- periodic (transverse)
- thermal (longitudinal)

$$T_h \sim \frac{m_e}{2}\left(\frac{\omega}{k}\right)^2 \sim 20 \cdot T_e$$

TC8857

Also see talk for J. F. MYatt at this conference

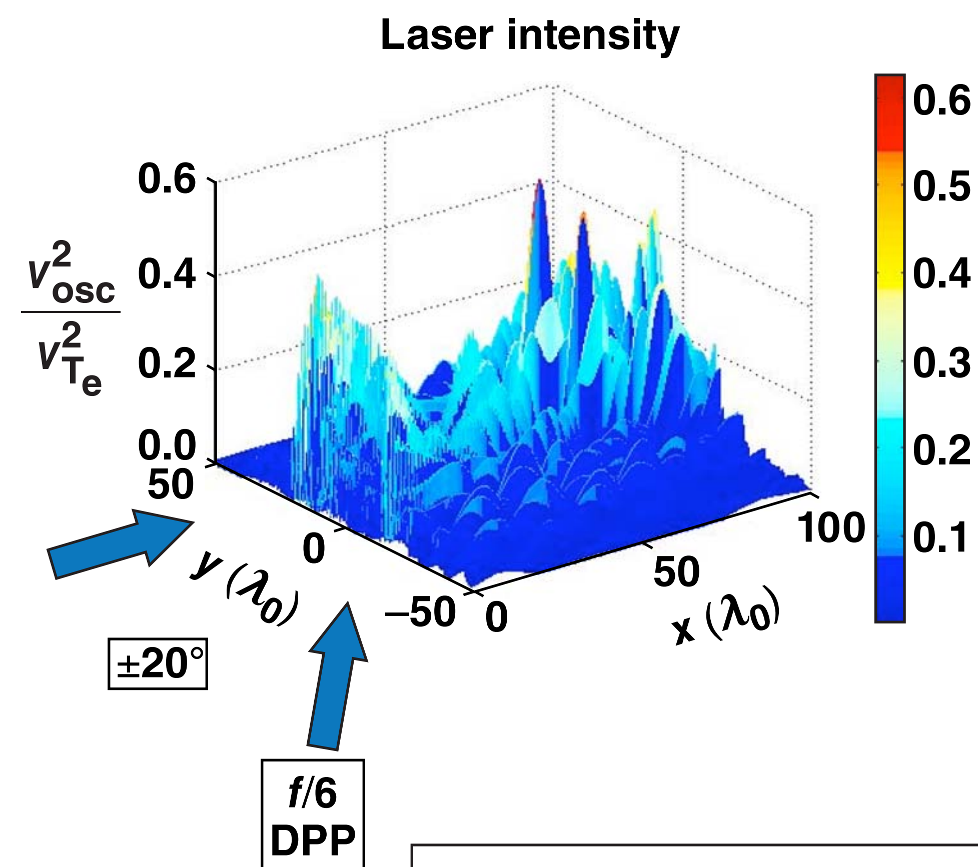
The plasma spectral density characterizes the low-frequency density perturbations driven by the ponderomotive force

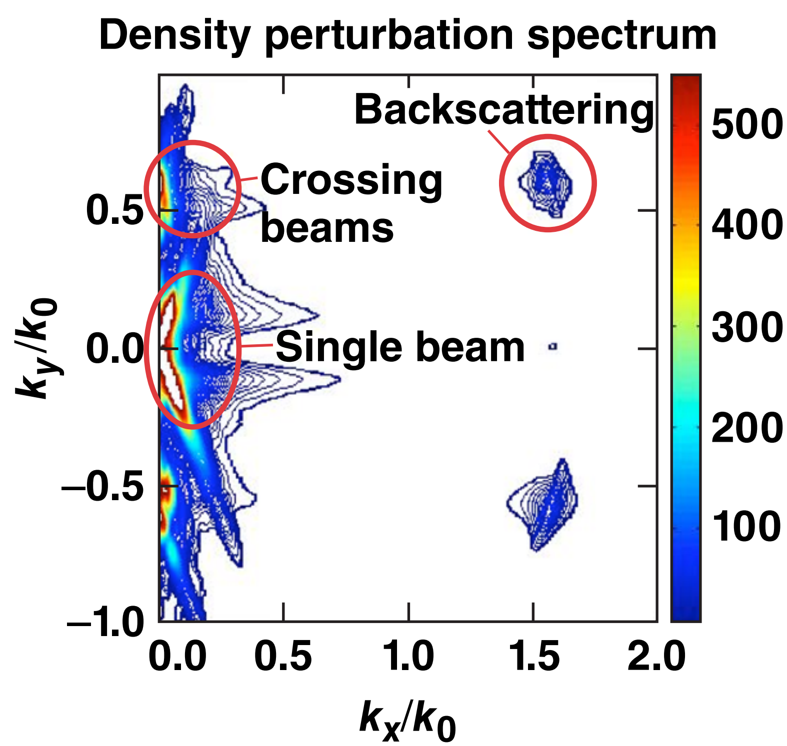


$$\text{Spectral density } \frac{S}{\omega} = \text{Im}\left[\frac{(\delta n_e/n_e)_{\omega,k}}{|E|^2_{\omega,k}/16\pi n T_e}\right]$$

TC8475a

The interaction of incoherent laser beams with plasmas produces low-frequency perturbations in electron density

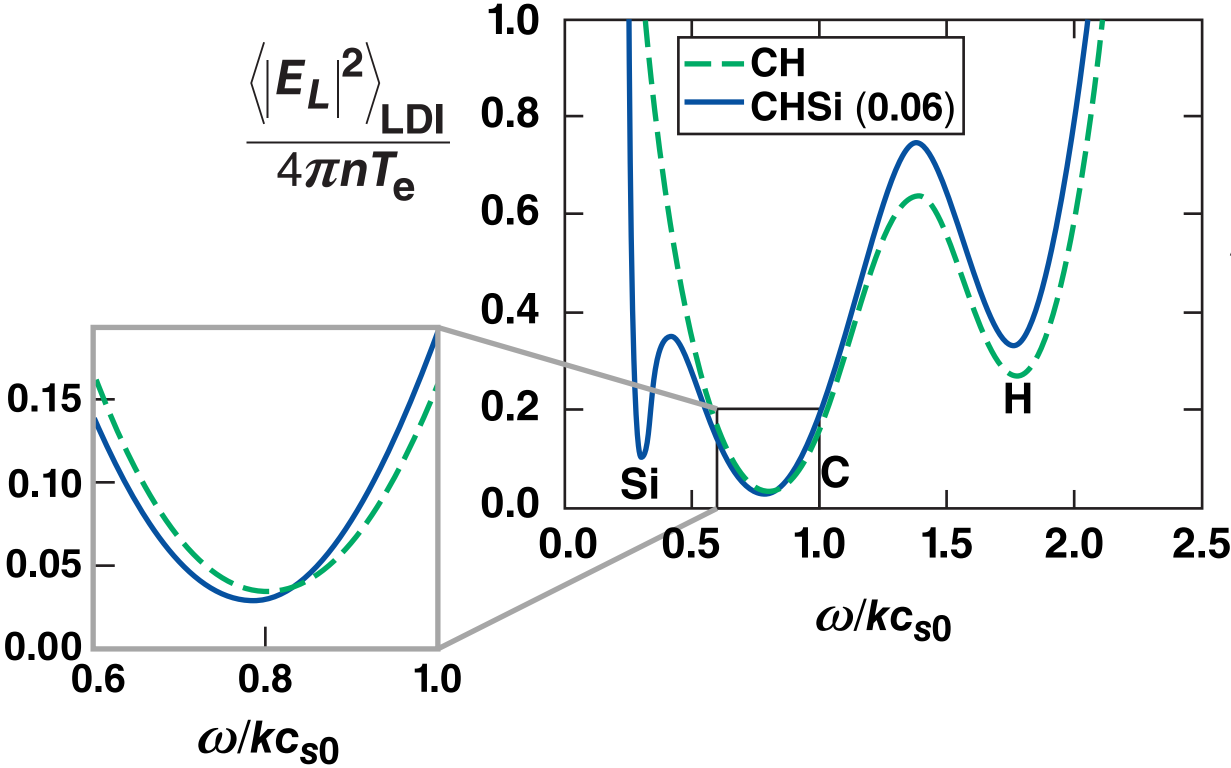




$$\langle I \rangle = 9 \times 10^{14}\ \mathrm{W/cm^2},\ T_e = 2\ \mathrm{keV},\ n_0 \approx \frac{n_c}{4}$$

TC8683a

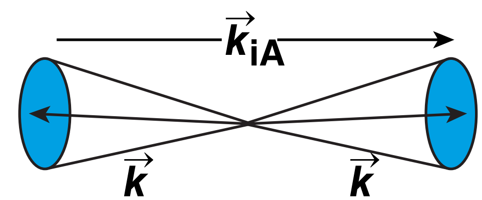
The threshold of the Langmuir decay instability depends on the characteristics of ion-acoustic waves



LDI threshold in the random-phase approximation

$$\frac{\langle |E_L|^2 \rangle}{16\pi n T_e} \cdot \left| \frac{S}{\omega} \right| = \frac{|\Delta\omega|}{\omega_p} \cdot 4$$

$\Delta\omega$ = resonance width



Seeding by laser-driven perturbations

TC8476b

Summary/Conclusions

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