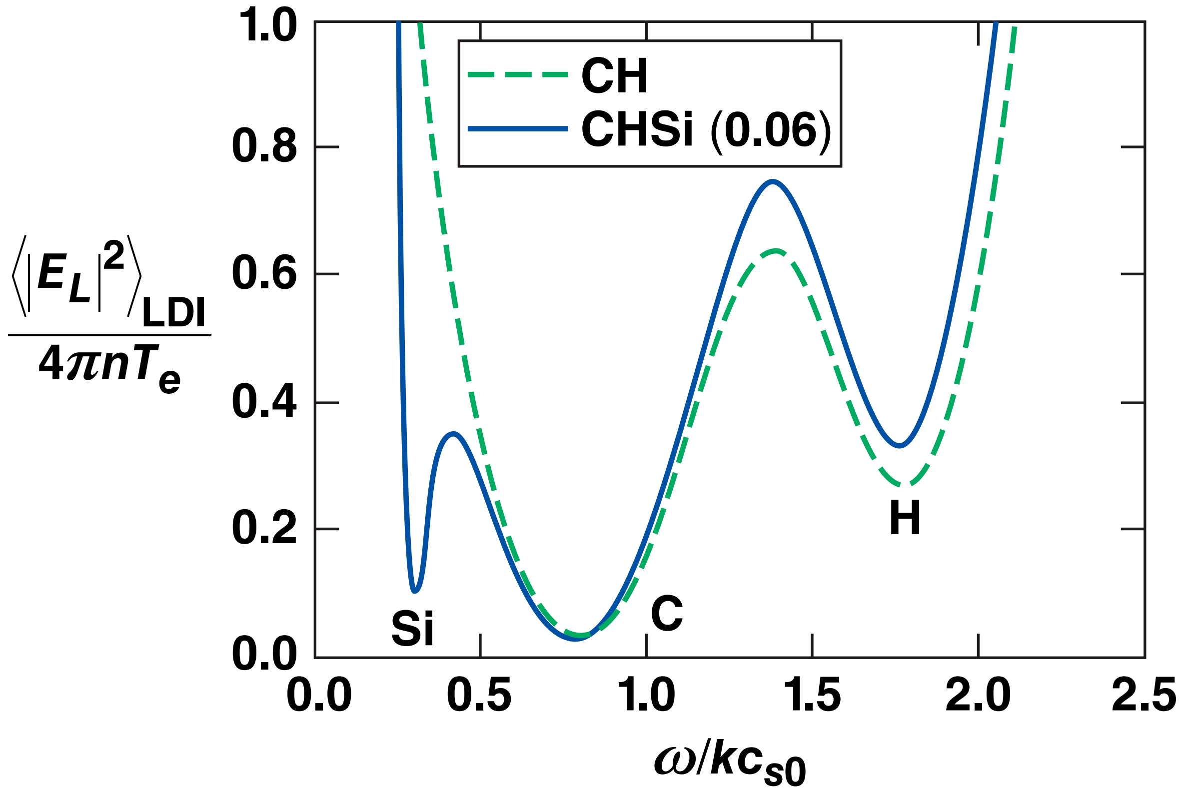
# Modeling of Two-Plasmon-Decay Instability Under Crossed-Beam Irradiation





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Summary

# The multispecies composition of plasmas can increase the threshold of the two-plasmon-decay instability (TPD) and decrease the instability saturation level

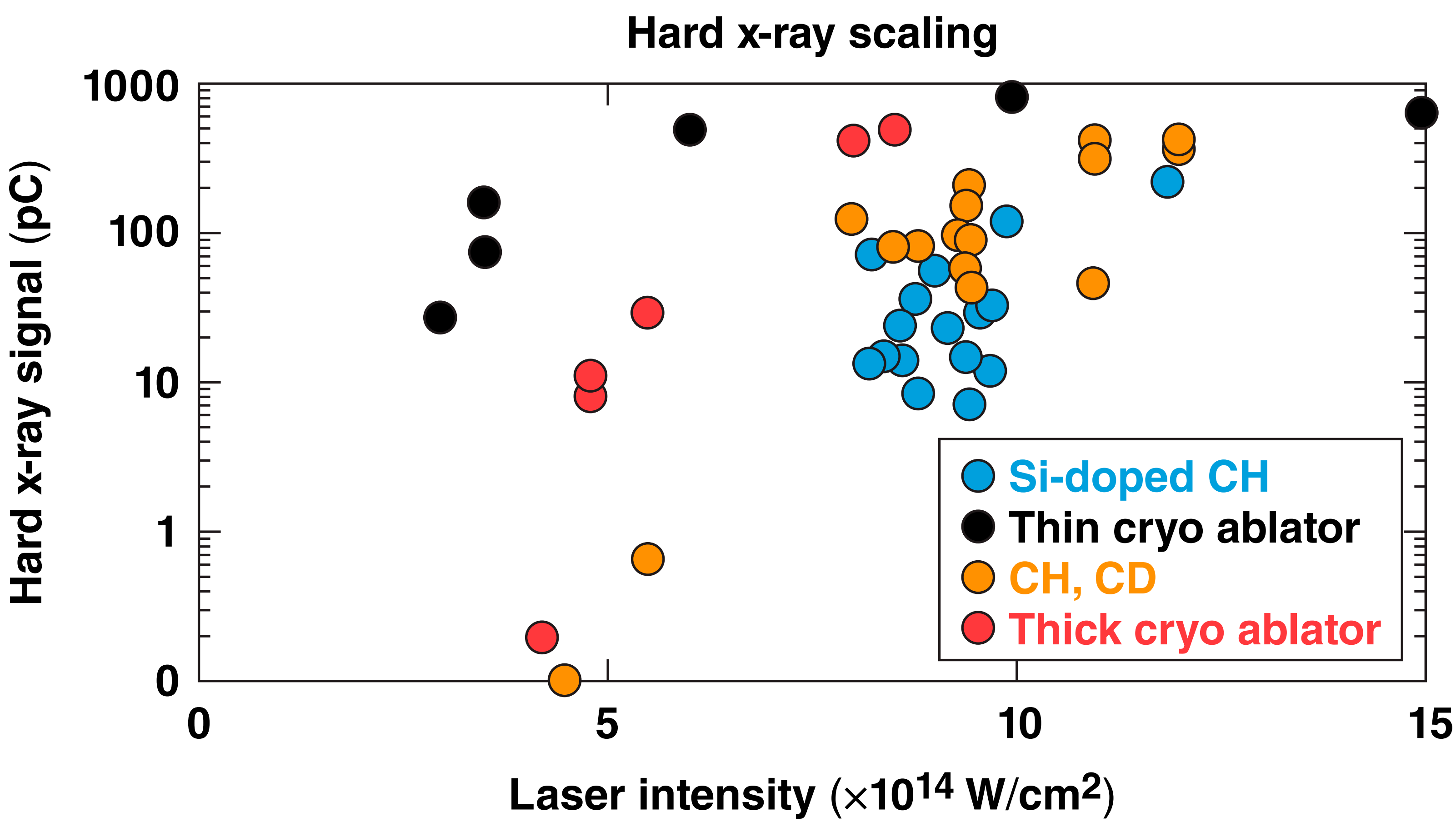
UR LLE

- The linear stage of TPD driven by crossed laser beams produces a broad angular spectrum of primary Langmuir waves.
- In multispecies plasmas, the presence of a high-Z dopant modifies the dispersion properties and can increase the amplitude of density perturbations.
- The increase in the density perturbation amplitude leads to the decrease of the threshold of Langmuir Decay Instability and to the saturation of the TPD at a lower level.

# Outline

1. The linear stage of TPD growth
2. The modification of the ion-acoustic dispersion characteristics in multispecies plasmas
3. The influence of these characteristics on the Langmuir Decay Instability and, therefore, on the TPD saturation

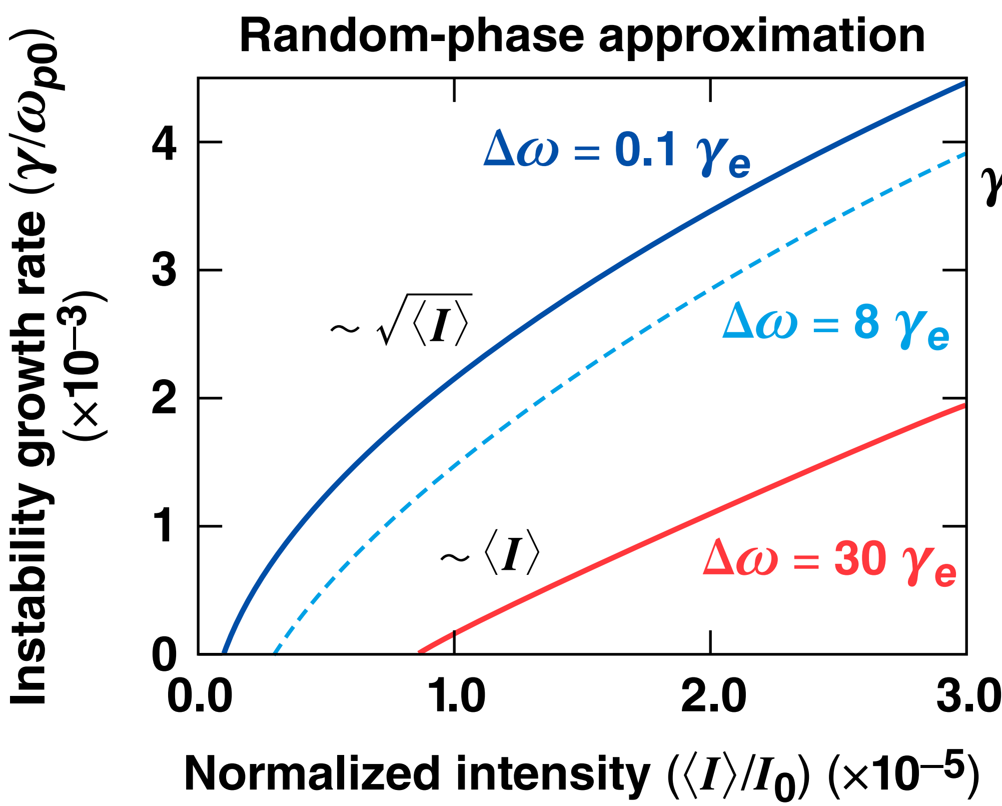
# In OMEGA experiments, the hard x-ray production depends on the overlapped intensity of multiple incoherent laser beams



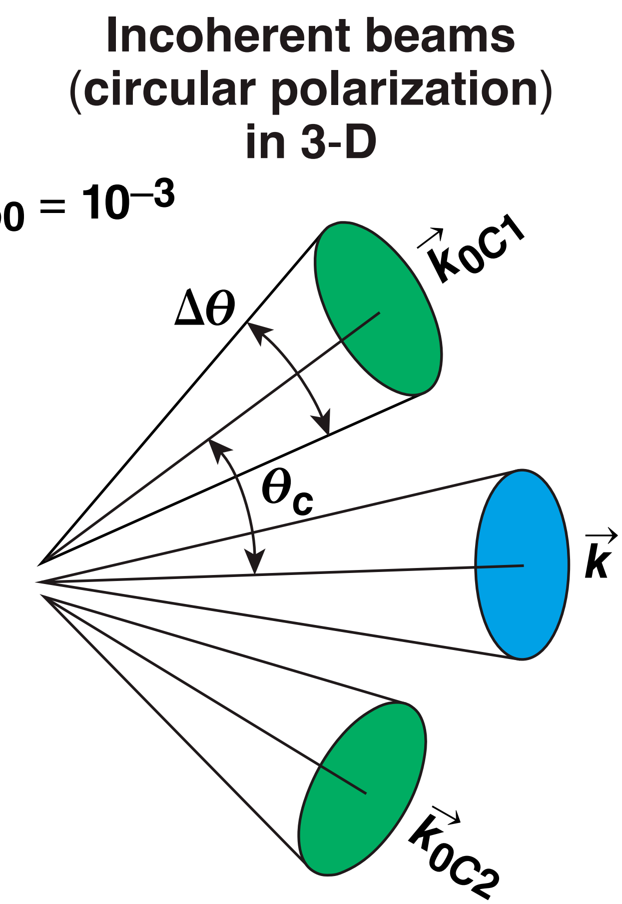

TC8036

# The increase of the angular width of an incoherent laser beam leads to the decrease of TPD growth rate and to the increase of the threshold






$\gamma_e/\omega_{p0} = 10^{-3}$




$(\gamma + \gamma_e)/\omega_{p0} \equiv \sqrt{\langle I \rangle / I_0}$ at $\Delta\omega = 0$

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

TC7798a

# For parameters of OMEGA plasmas, the TPD instability threshold is influenced by the interplay of plasma inhomogeneity, wave damping and resonance detuning due to beam incoherence

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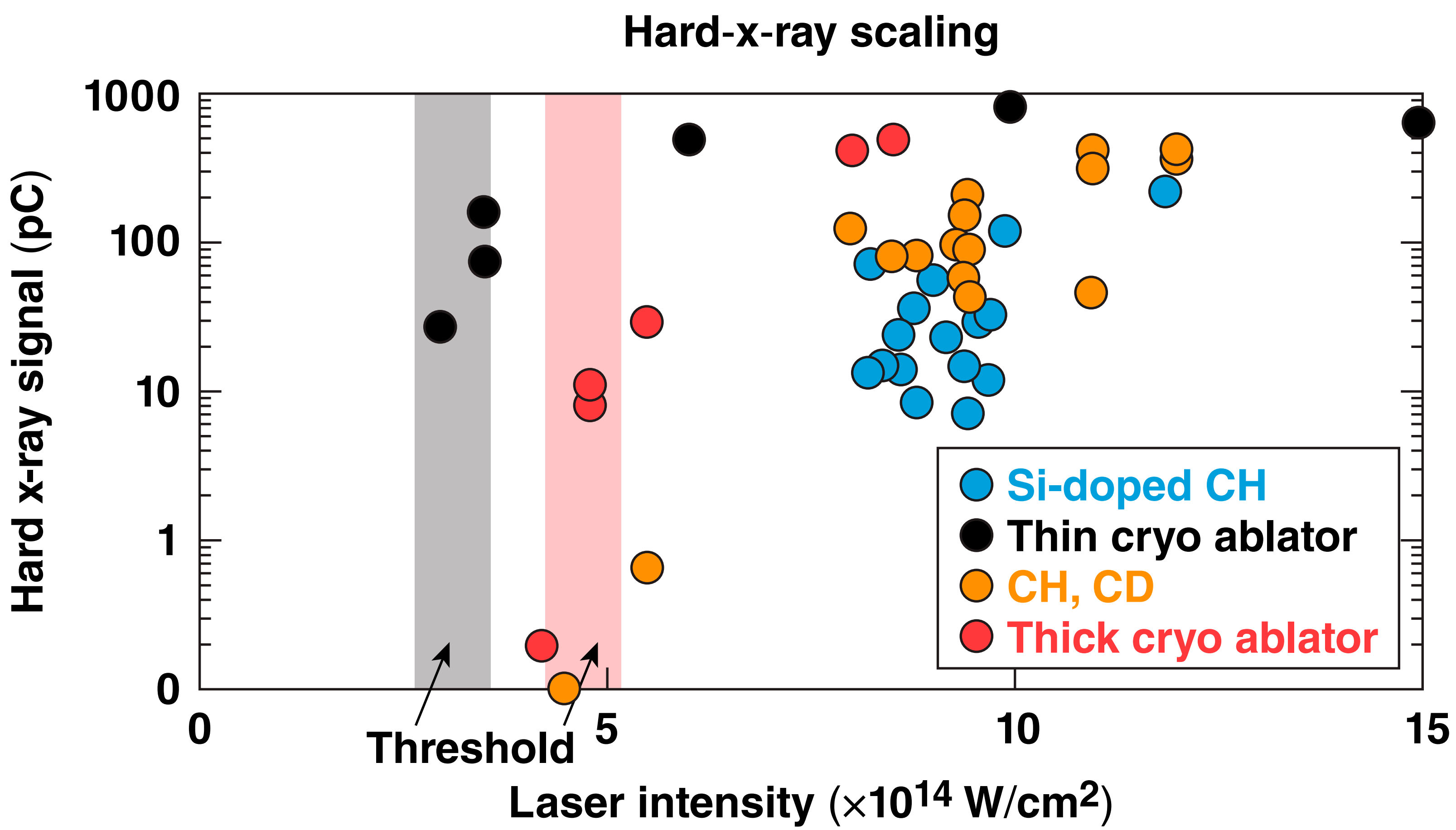
- **Plasma wave damping** $$\left(\frac{\gamma_e}{\omega_{p0}}\right)_{coll} = 0.5 \times 10^{-3} \frac{(Z/5.3)}{(T_e/2\ \text{keV})^{3/2}}$$
- **Detuning due to inhomogeneity** $$\frac{1}{2\,k_0 L} = \frac{2.1 \times 10^{-4}}{(L/150\ \mu m)}$$

$$\Updownarrow$$

- **Homogeneous 3-wave growth rate** $$\gamma^0 = \frac{k_0 |V_0|}{\omega_{p0}} = 0.26 \times 10^{-2} \sqrt{I_{14}}$$
- **Detuning due to beam incoherence** $$\frac{\Delta\omega}{\omega_{p0}} = 4 \times 10^{-2} (T_e/2\ \text{keV})\, \Delta\theta \sin\theta_c$$

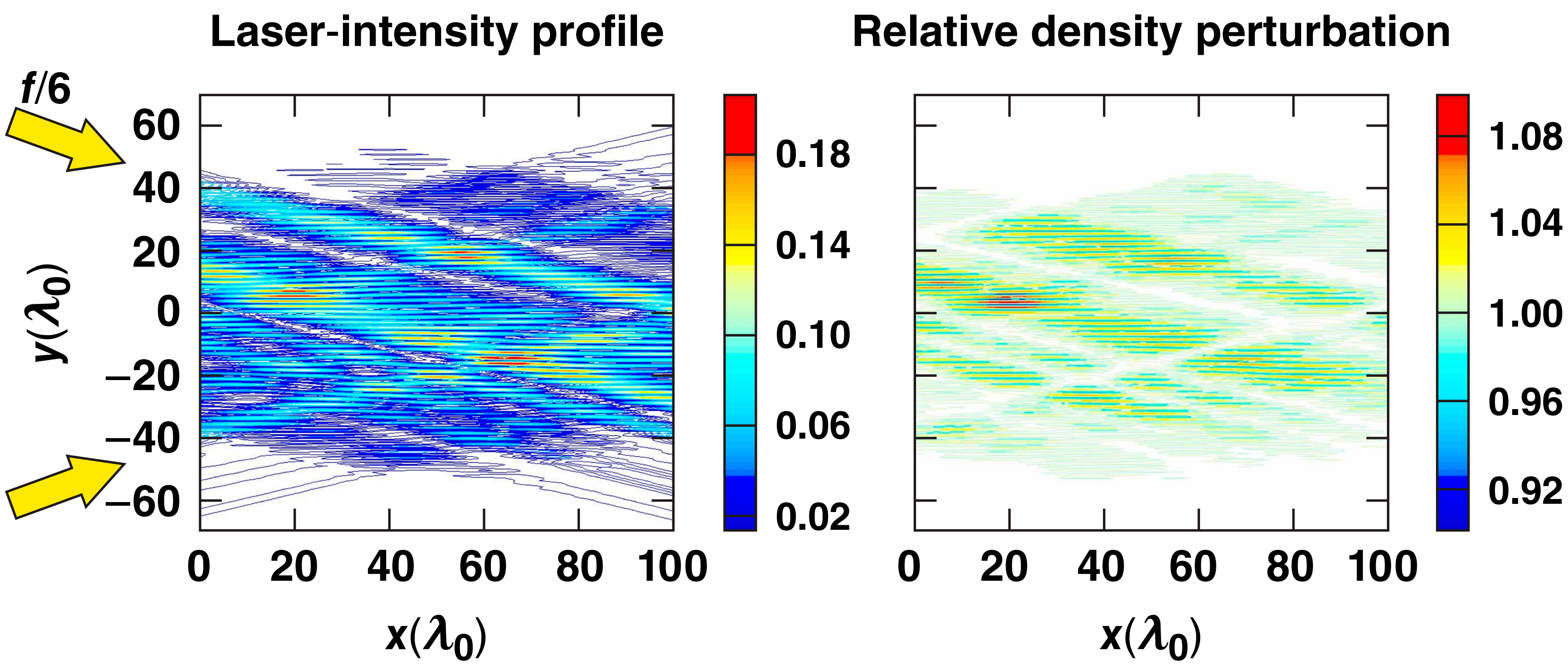
TC7846

# In OMEGA experiments, the target preheat depends on the overlapped intensity of multiple incoherent laser beams




TC7797b

# Low-frequency perturbations in electron density are produced by the interaction of incoherent laser beams with plasmas




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

$$\left(\frac{n_e}{n_0} - 1\right) \sim \frac{I}{\langle I \rangle}$$

**When ion-acoustic damping decreases, perturbation amplitude increases.**

TC7801c

# In plasmas with multispecies ions, the ion–ion collision frequency includes collisions with all ion species

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- Collision integral $\delta J_{i\Sigma} = \sum_A \delta J_{iA}, \left( \delta J_{iA} \sim \frac{e_i^2 e_A^2}{T_i^{3/2} m_{\text{eff}}^{1/2}} \right)$ and $\nu_{i\Sigma} = \frac{4 \ln \Lambda}{3\sqrt{\pi}} \frac{e_i^2}{T_i^{3/2}} \sum_A \left( \frac{n_A e_A^2}{m_{\text{eff}}^{1/2}} \right)$

The ion heat flux $\vec{q}^{\Sigma} = \sum_i \vec{q}^{i} = -\kappa_{\Sigma} \frac{\partial T_i}{\partial \vec{r}}$

Ion heat conductivity* $\kappa_{\Sigma} = \sum_i 3.9 \frac{n_i T_i}{m_i \nu_{i\Sigma}} \sim \frac{\sum_i \left( n_i / e_i^2 m_i \right)}{\sum_i \left( n_i e_i^2 / m_{\text{eff}}^{1/2} \right)} T_i^{5/2}$

- Ion viscosity* $\eta^{\Sigma} = \sum_i 0.96 \frac{n_i T_i}{\nu_{i\Sigma}} \sim \frac{\sum_i \left( n_i / e_i^2 \right)}{\sum_i \left( n_i e_i^2 / m_{\text{eff}}^{1/2} \right)} T_i^{5/2}$

*S. I. Braginskii, in *Reviews of Plasma Physics,* edited by Acad. M. A. Leontovich (Consultants Bureau, New York, 1965), Vol. 1, p. 205.

TC8357

# The coefficients for ion heat conductivity, and ion viscosity are significantly modified when the plasma composition changes

| | $\frac{\nu_{e\Sigma}}{\sqrt{2}\,\nu_{ee}} = Z_{eff}$ | $\frac{\nu_T^{\Sigma}}{\sqrt{2}\,\nu_{ee}}$ | $\frac{\kappa_{\Sigma}}{\kappa_{D_2}}$ | $\frac{\eta^{\Sigma}}{\eta_{D_2}}$ |
|---|---|---|---|---|
| $D_2$ | 1.0 | 0.50 $(m/m_p)$ | 1.000 | 1.000 |
| CD | 5.3 | 0.50 $(m/m_p)$ | 0.032 | 0.027 |
| CHSi(0.06) | 7.1 | 0.56 $(m/m_p)$ | 0.032 | 0.017 |

- The rate of energy transfer between electrons and ions

$$\nu_T^{\Sigma} = \sum_i 2\frac{m}{m_i}\nu_{ei}$$

(~10% to 20% of ohmic heating for $D_2$)

TC8148a

# The dispersion equation for ion-acoustic waves in multispecies plasmas includes a sum of contributions from different ion species

$$\frac{k^2 c_{s0}^2}{n_e} \sum_i \frac{Z_i^2 n_i / M_i}{(\omega - \vec{k}\,\vec{V})^2 + 2i\gamma_i(\omega - \vec{k}\,\vec{V}) - (5/3)\,k^2 V_{Ti}^2} = 1$$

Fluid model

- $\vec{V}$-flow velocity; $Z_i$ and $M_i$ -ion charge and mass; $c_{s0}^2 = (T_e / m_p)$
- In the collisional (i–i) regime, the ion-acoustic damping is determined by the ion viscosity and ion heat conductivity.

$$\gamma_i = k^2 \left(0.64 + 0.87 \frac{V_{Ti}^2}{c_s^2}\right) \frac{V_{Ti}^2}{\nu_{i\Sigma}}$$

$$\frac{1}{k} \geq \frac{c_s}{\nu_{i\Sigma}}$$

Strong collisions

TC8360a

# The dispersion equation for ion-acoustic waves in multispecies plasmas has several solutions

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$(T_i / T_e) = 1$

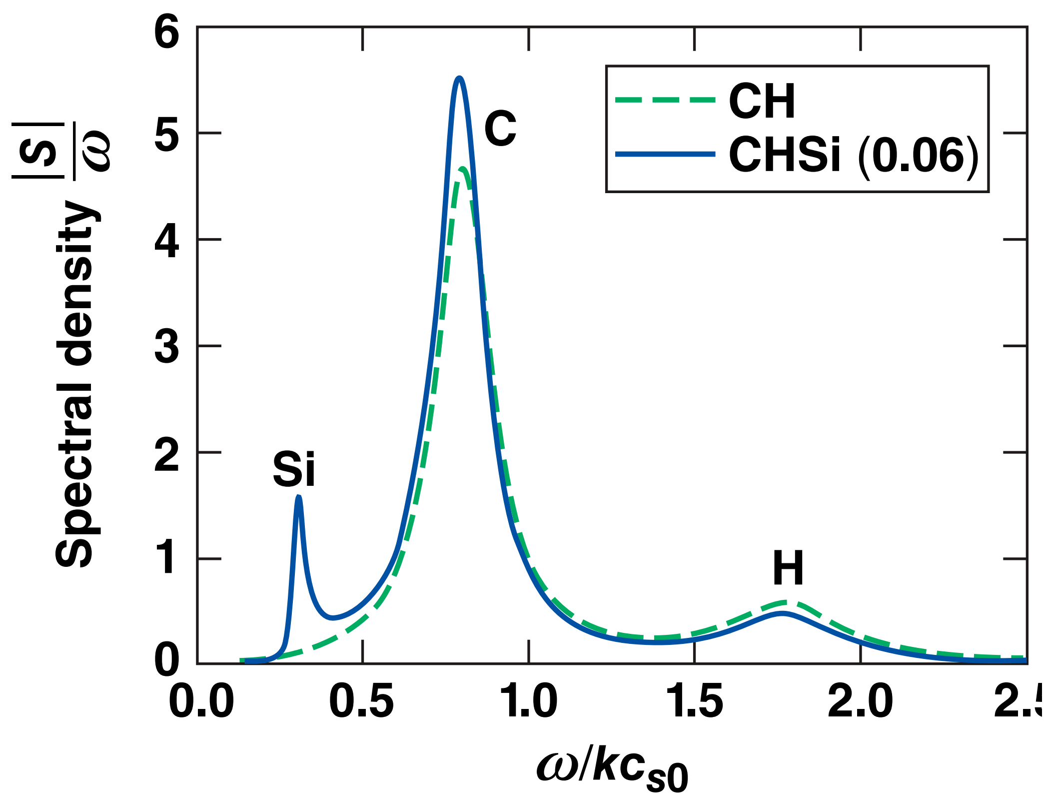
- For CHSi (0.06) the solutions are:

$$\left(\omega_r - \vec{k}\,\vec{V}\right)^2 = 0.94\,k^2 c_{s0}^2 \quad \text{and} \quad \gamma_i \approx \gamma_H$$

$$\left(\omega_r - \vec{k}\,\vec{V}\right)^2 = 0.43\,k^2 c_{s0}^2 \quad \text{and} \quad \gamma_i \approx 0.68\,\gamma_C + 0.32\,\gamma_{Si}$$

$$\left(\omega_r - \vec{k}\,\vec{V}\right)^2 = 0.04\,k^2 c_{s0}^2 \quad \text{and} \quad \gamma_i \approx \gamma_{Si}$$

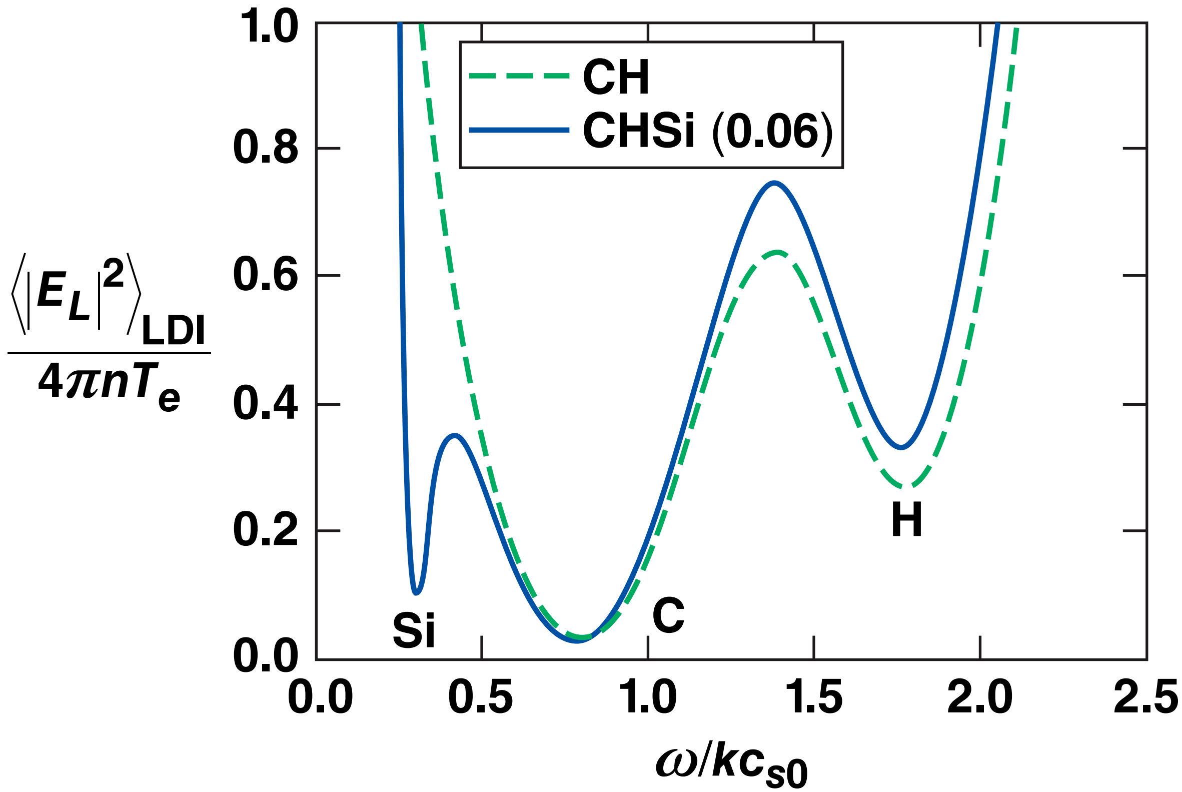
# The plasma spectral density characterizes the low-frequency density perturbations driven by the ponderomotive force




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

TC8475

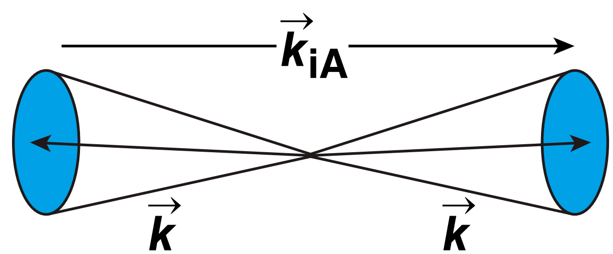
# The threshold of the Langmuir Decay Instability depends on the characteristics of ion-acoustic waves




**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




TC8476

Summary/Conclusions

# The multispecies composition of plasmas can increase the threshold of the two-plasmon-decay instability (TPD) and decrease the instability saturation level

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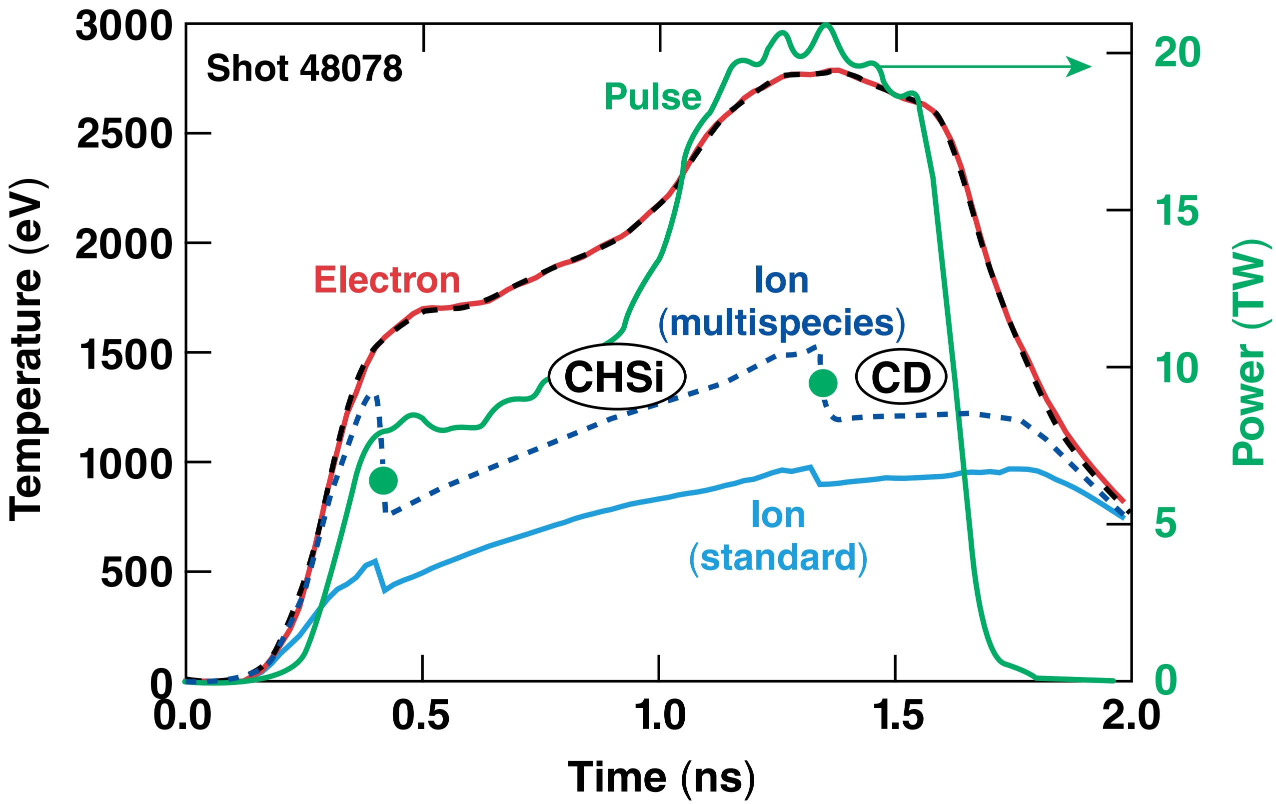
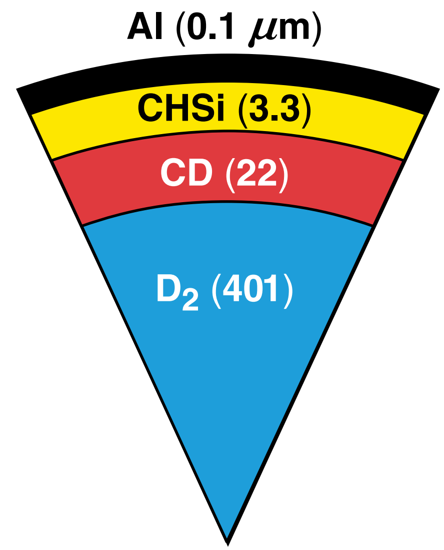
# The influence of multispecies effects on the plasma parameters has been studied with *LILAC*

UR LLE

- Temperatures at quarter-critical density




TC8149a

# The multi-species composition of plasmas influences the hydrodynamic equations

UR LLE

$$\partial_t \rho + \vec{\nabla}(\rho \vec{V}) = 0$$

ion density $n_\Sigma = \sum_i n_i$

mass density $\rho = \sum_i n_i m_i$

$$\rho\left[\partial_t V_j + (\vec{V}\cdot\vec{\nabla})V_j\right] = -\nabla_j(n_e T_e + n_\Sigma T_i) - \nabla_k \sigma_{jk}^{\Sigma} - \frac{e^2}{4m\omega_0^2}\left\{n_e \nabla_j |E|^2 - \nabla_k\left[n_e\left(E_k E_j^* + E_j E_k^*\right)\right]\right\}$$

Ion

Electron

$$\partial_t T_e + (\vec{V}\cdot\vec{\nabla})T_e + \frac{2T_e}{3}\vec{\nabla}\cdot\vec{V} + \frac{2}{3n_e}\vec{\nabla}\cdot\vec{q}^{e} = \frac{e^2|E|^2 \nu_{e\Sigma}}{3m\,\omega_0^2} - \sum_i \frac{2m\,\nu_{ei}}{m_i}(T_e - T_i)$$

Electron–Ion

$$\partial_t T_i + (\vec{V}\cdot\vec{\nabla})T_i + \frac{2T_i}{3}\vec{\nabla}\cdot\vec{V} + \frac{2}{3n_\Sigma}\vec{\nabla}\cdot\vec{q}^{\Sigma} = \sum_i \frac{2m\,\nu_{ei}}{m_i}(T_e - T_i)$$

- The ion temperatures of different species are assumed to be the same.

TC8144