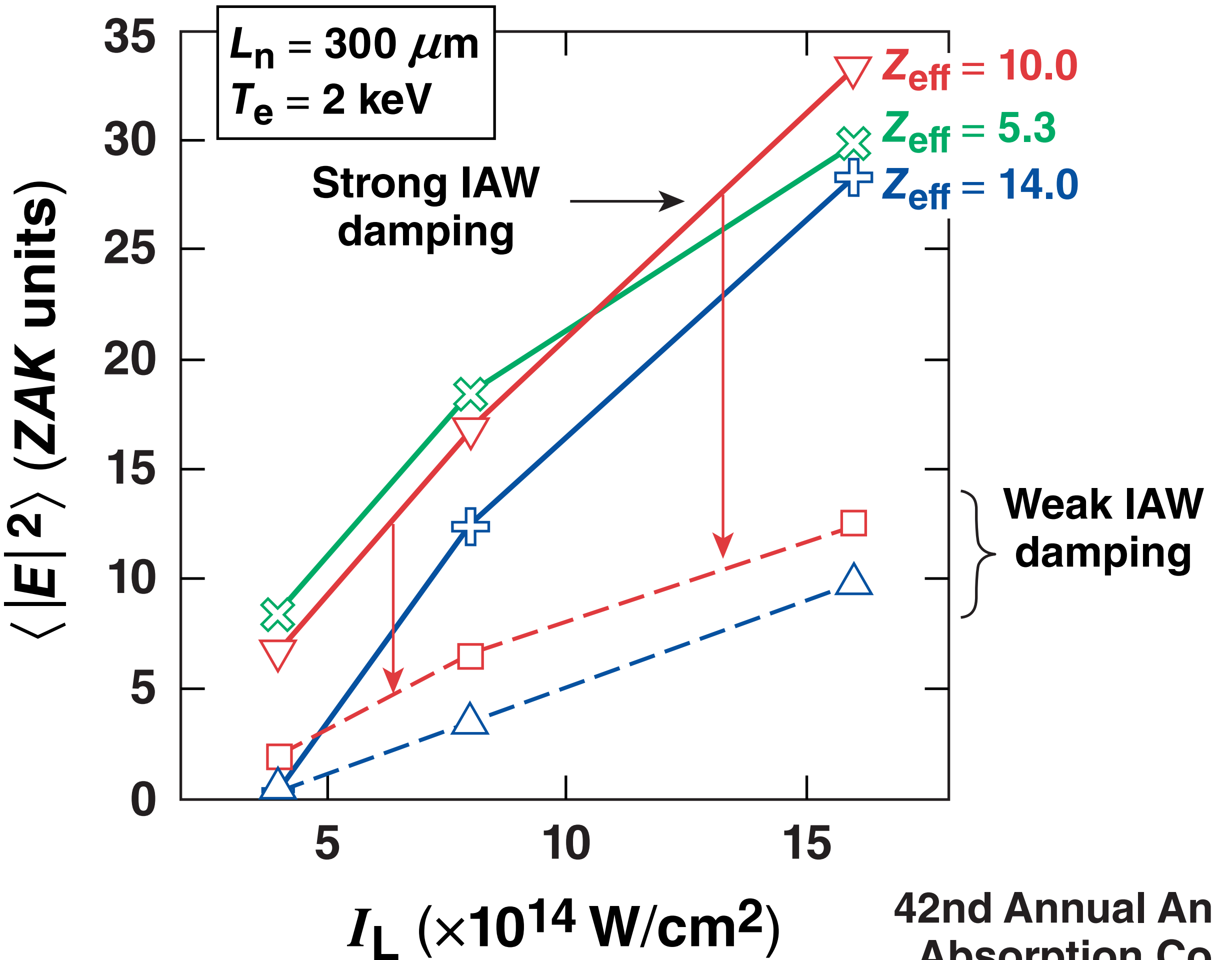
The Mitigating Effect of Wave Dissipation on Hot-Electron Generation Caused by Two-Plasmon Decay (TPD) in Inhomogeneous Plasmas

$$\eta = \frac{I_{14} L_n}{230\, T_e}$$



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Summary

TPD preheat can be reduced through the manipulation of the collisional and Landau damping of Langmuir and ion-acoustic waves

- Langmuir wave (LW) collisional damping has an impact on the growth rate/thresholds [in addition to the hydrodynamic variables (Δn_e, T_e)]
  - importance increases with the scale length
- Nonlinear saturation is sensitive to plasma composition ($\langle Z \rangle$, T_i, $\langle Z \rangle^2$) via the ion-acoustic damping rate
  - predictions with the 2-D code *ZAK**
  - hot-electron predictions with the 2-D code *QZAK***
  - suggestions for planar experiments

*D. F. DuBois *et al*., Phys. Rev. Lett. 74, 3983 (1995);
D. A. Russell and D. F. DuBois, Phys. Rev. Lett. 86, 428 (2001).
**D. A. Russell *et al*., "Two-plasmon-decay turbulence driven by the shared-wave triad of two crossed beams," this conference.

TC10023

Collaborators

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The *ZAK* model of TPD is used to predict linear instability and nonlinear saturation caused by density fluctuations

- "Extended" Zakharov equations used in *ZAK**

Gradient threshold

$$\nabla \cdot \left[D_{LW} - \omega_0^2 (\delta n + \delta N)/n_0\right] E = (e/4m_c)\nabla \cdot \left[\nabla (E_0 \cdot \bar{E}) - E_0 \nabla \cdot \bar{E}\right] + S_E$$

$$D_{IAW} \delta n = \nabla^2 \left(|E|^2 + \frac{1}{4}|E_0|^2\right) \Big/ (16\pi M_i) + S_{\delta n}$$

TPD source term

Dispersion relations for LW and IAW

Collisional threshold

$$D_{LW} = \left[2i\omega_{p0}(D_t + \nu_e *) + 3\nu_e^2 \nabla^2\right]$$

$$D_{IAW} = \left(D_t^2 + 2\nu_i * D_t - c_s^2 \nabla^2\right)$$

*D. F. DuBois *et al.*, Phys. Rev. Lett. 74, 3983 (1995); D. A. Russell and D. F. DuBois, Phys. Rev. Lett. 86, 428 (2001).

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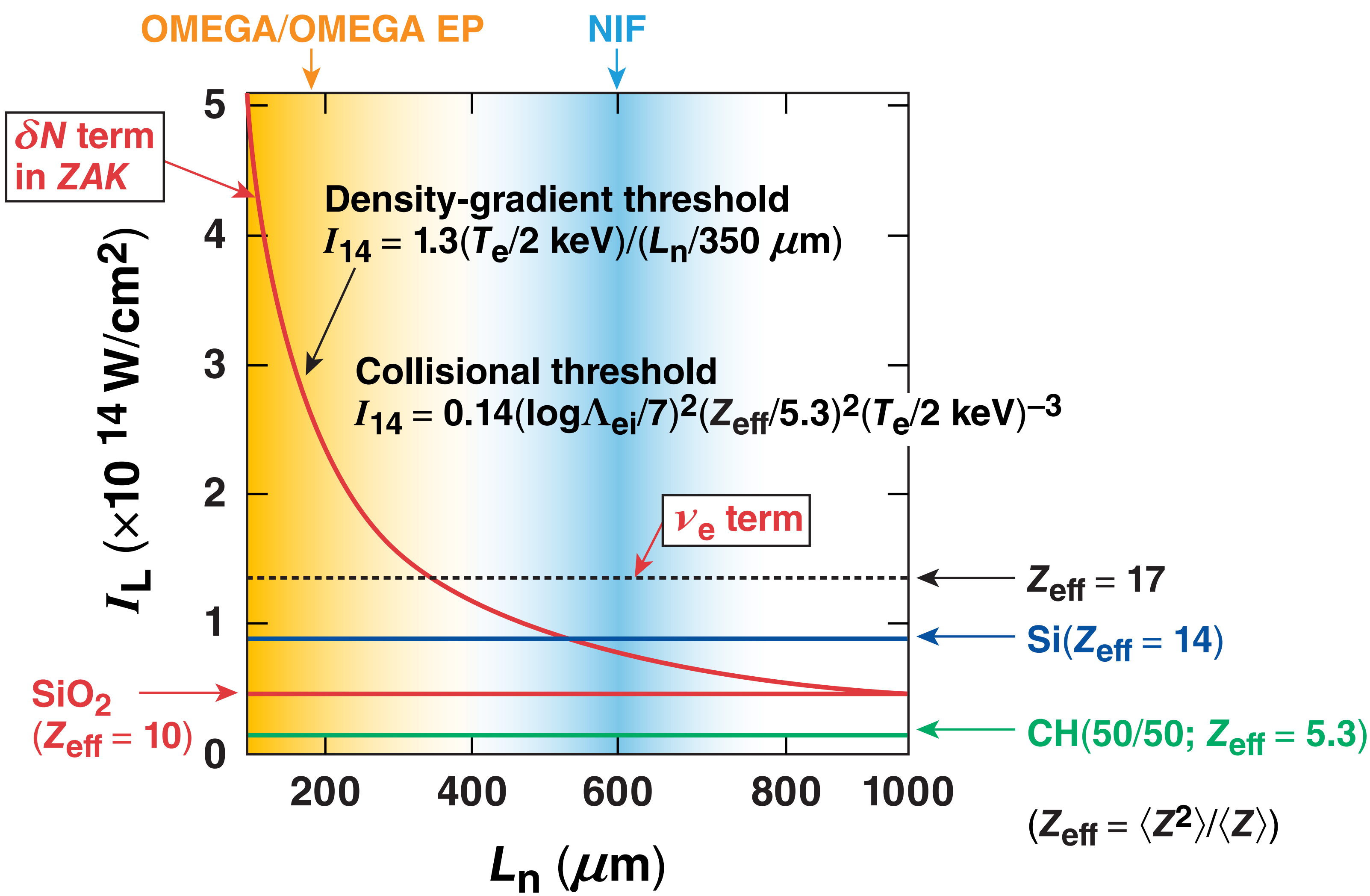
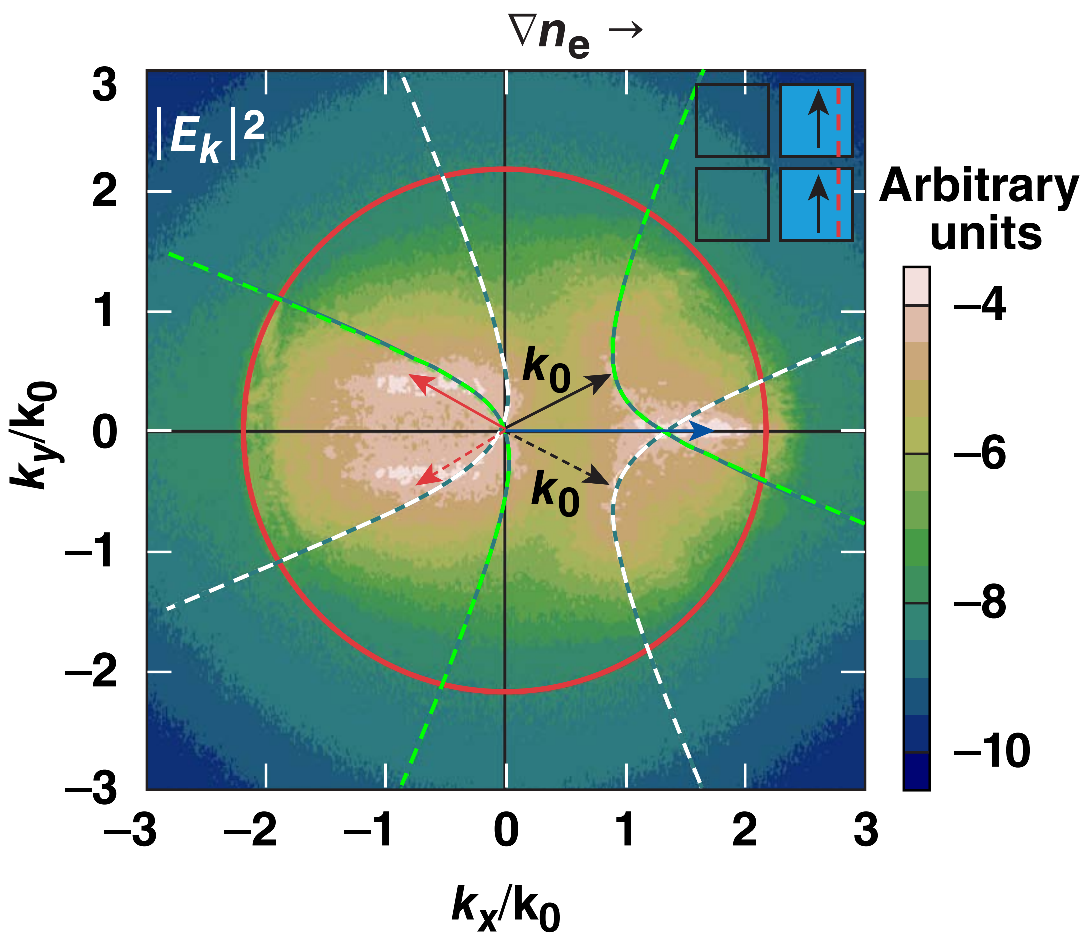
The collisional TPD threshold can be made to exceed the gradient threshold (for Si at ignition scale)



Two-dimensional *ZAK* calculations assume two overlapped plane electromagnetic (EM) waves* polarized in their plane of incidence

- This has the feature that TPD is driven unstable convectively even when the single-beam intensities are below threshold
- $\langle|E|^2\rangle$ is computed at saturation



*D. T. Michel *et al.*, "Experimental Demonstration of the Two-Plasmon-Decay Common-Wave Process," this conference.

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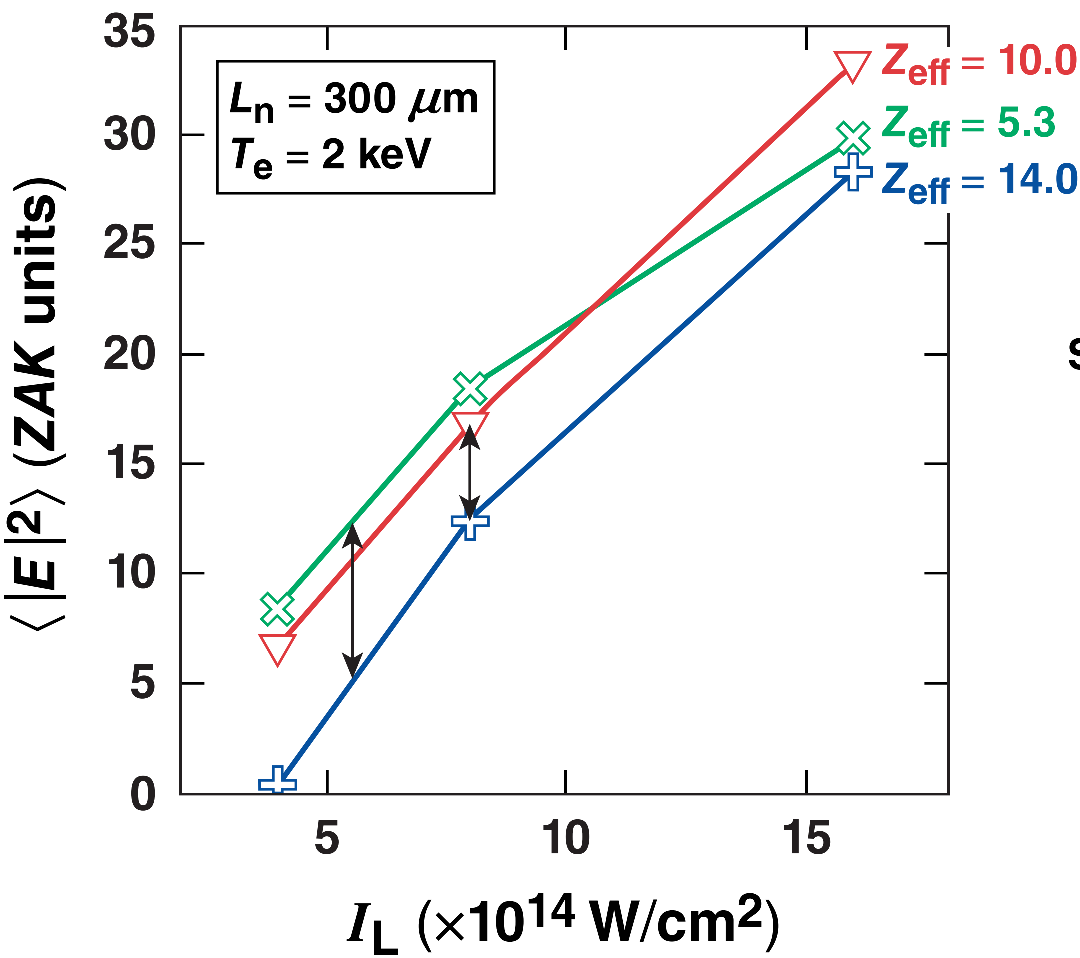
ZAK Calculations

Increased collisional damping of LW's leads to a lower saturated level of electrostatic fluctuations for $Z_{eff} = 14$

e–i collisions cut into the growth rate for $Z = 14$



Strong IAW damping ($\nu_i = 0.1$)

TC10038

R. Betti, "Advanced Ablator Target Designs for Shock and Hot Spot Ignition on the National Ignition Facility," this conference.

The nonlinear evolution of TPD in the *ZAK* model depends on the ion-acoustic damping rate ν_i

- "Extended" Zakharov equations used in *ZAK**

$$\nabla \cdot \left[D_{LW} - \omega_0^2(\delta n + \delta N)/n_0\right] E = (e/4m_c)\nabla \cdot \left[\nabla(E_0 \cdot \bar{E}) - E_0 \nabla \cdot \bar{E}\right] + S_E$$

$$D_{IAW}\delta n = \nabla^2\left(|E|^2 + \frac{1}{4}|E_0|^2\right) \Big/ (16\pi M_i) + S_{\delta n}$$

TPD source term

Dispersion relations for LW and IAW

$$D_{LW} = \left[2i\omega_{p0}(D_t + \nu_e) + 3\nu_e^2 \nabla^2\right]$$

$$D_{IAW} = \left(D_t^2 + 2\nu_i * D_t - c_s^2 \nabla^2\right)$$

Only important in the nonlinear stage

*D. F. DuBois *et al.*, Phys. Rev. Lett. 74, 3983 (1995);
D. A. Russell and D. F. DuBois, Phys. Rev. Lett. 86, 428 (2001).

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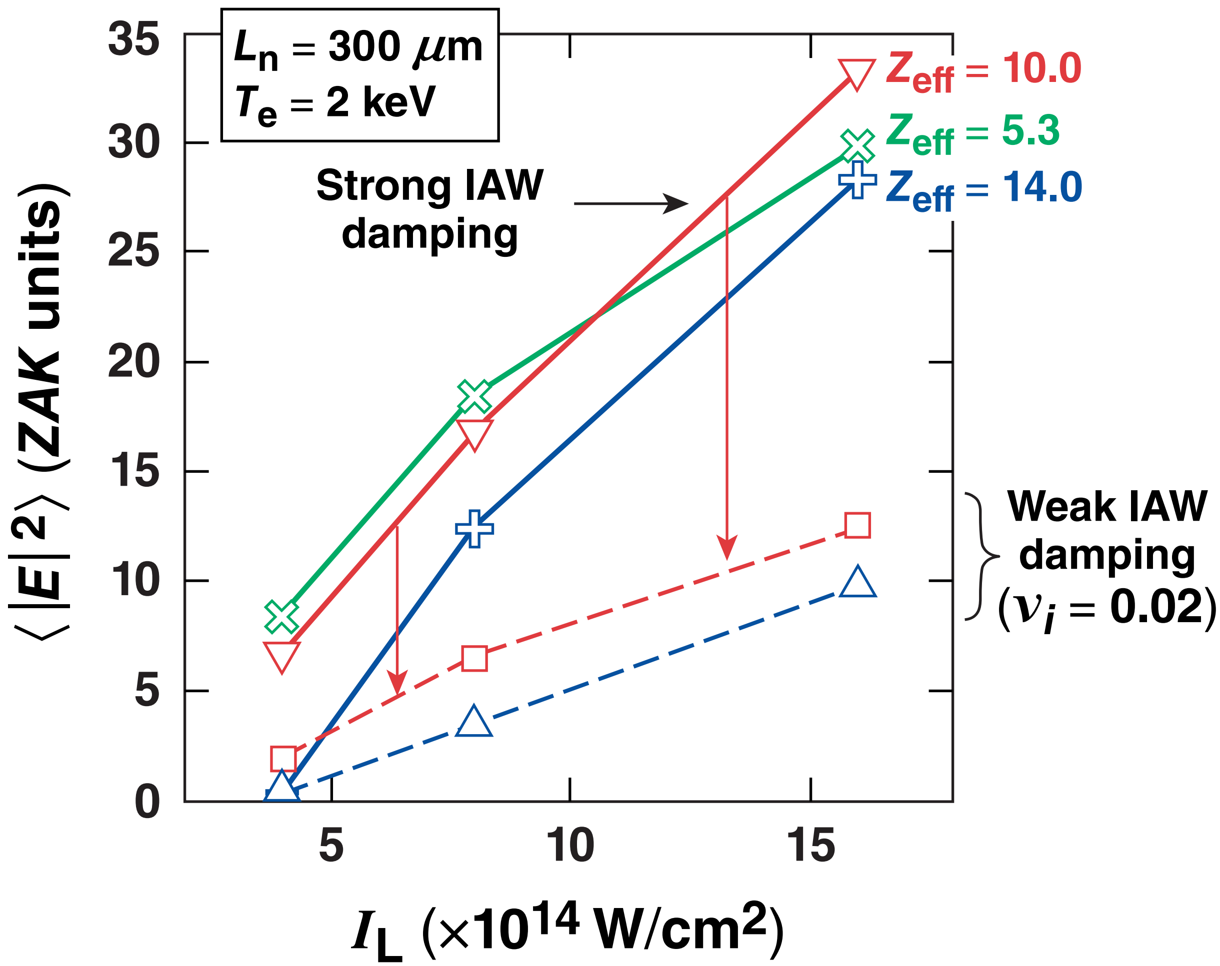
Decreasing the IAW damping leads to a dramatic reduction in the level of electrostatic fluctuations



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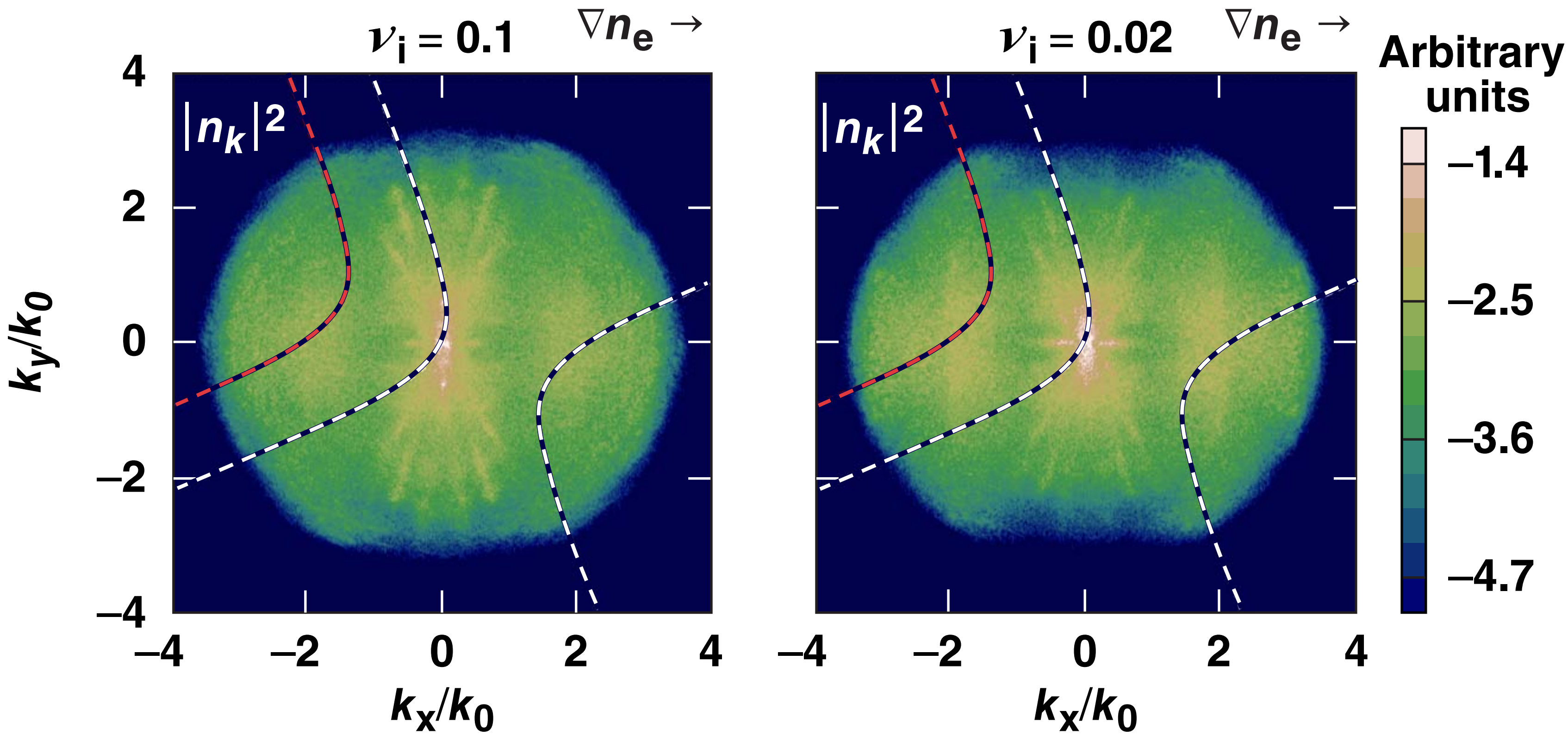
The reason that decreasing the IAW damping lowers the saturation level is not fully understood

- Langmuir-decay instability
- Ponderomotive response to unstable LW spectrum



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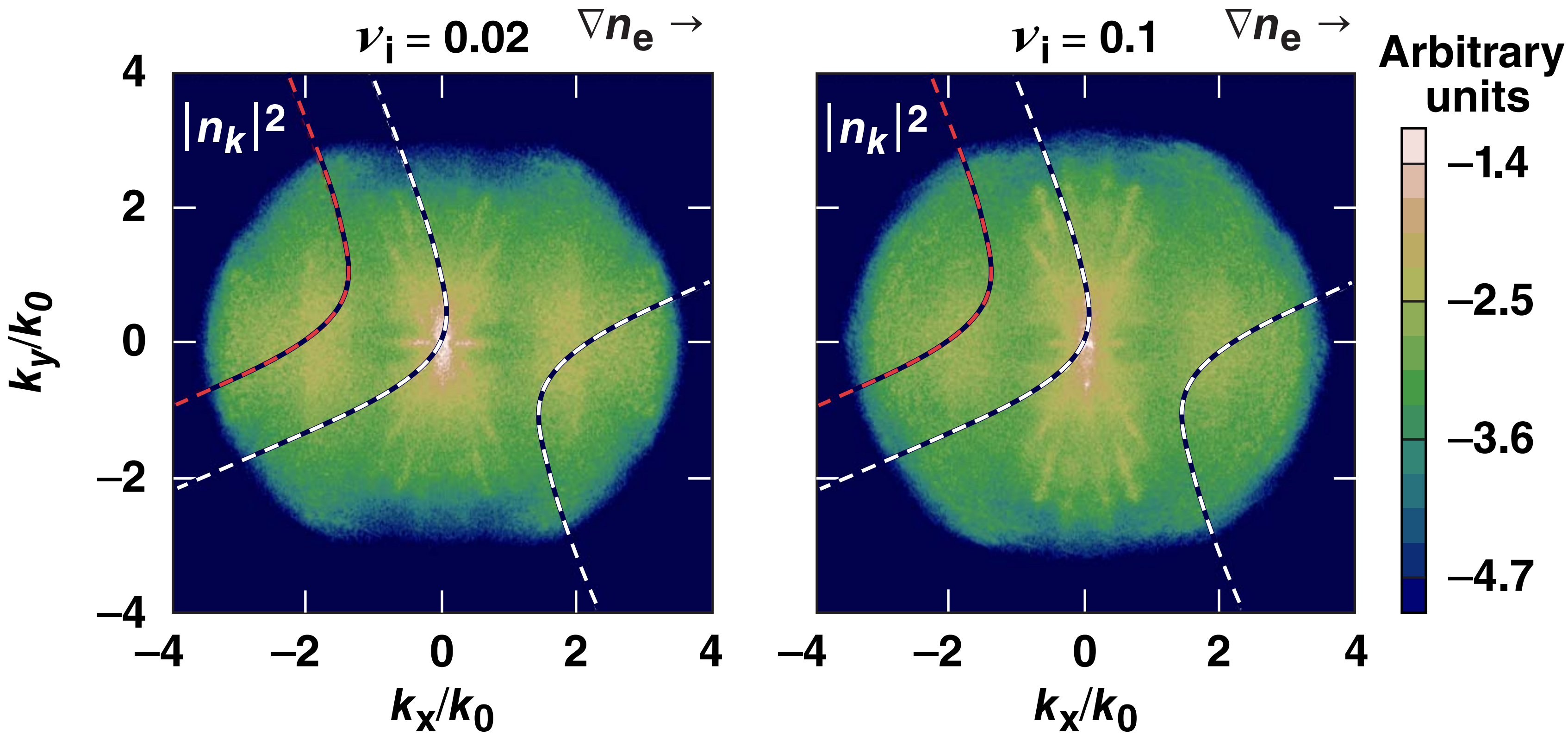
The reason that decreasing the IAW damping lowers the saturation level is not fully understood

- Langmuir-decay instability
- Ponderomotive response to unstable LW spectrum



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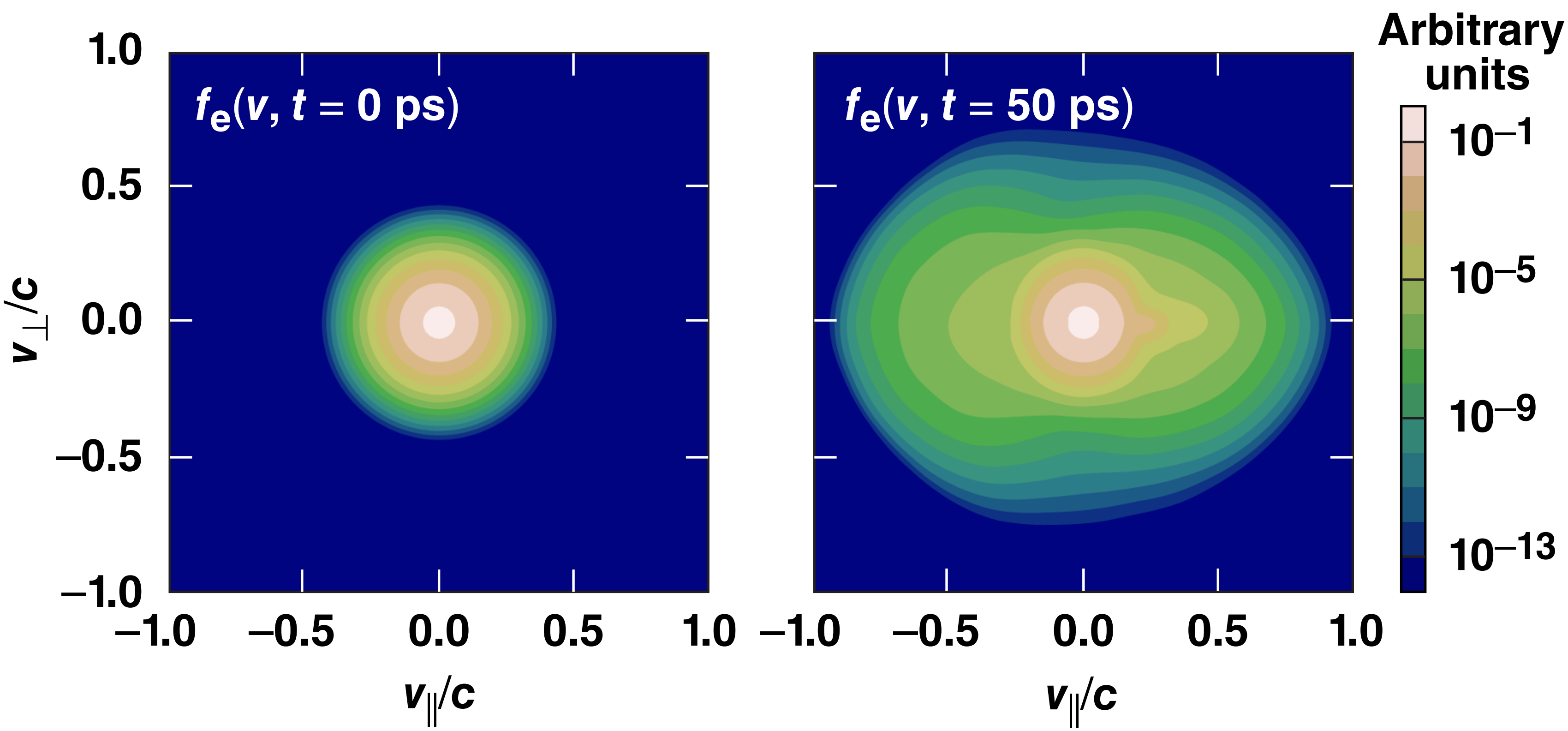
*QZAK** is an extension of *ZAK* to self-consistently include hot-electron generation in the quasilinear approximation

- The diffusion equation $\frac{\partial\langle f_e\rangle}{\partial t} + \frac{\partial}{\partial\vec{v}}\cdot\left(D(\vec{v})\cdot\frac{\partial\langle f_e\rangle}{\partial\vec{v}}\right) = \sigma(\langle f_e\rangle - f_M)$



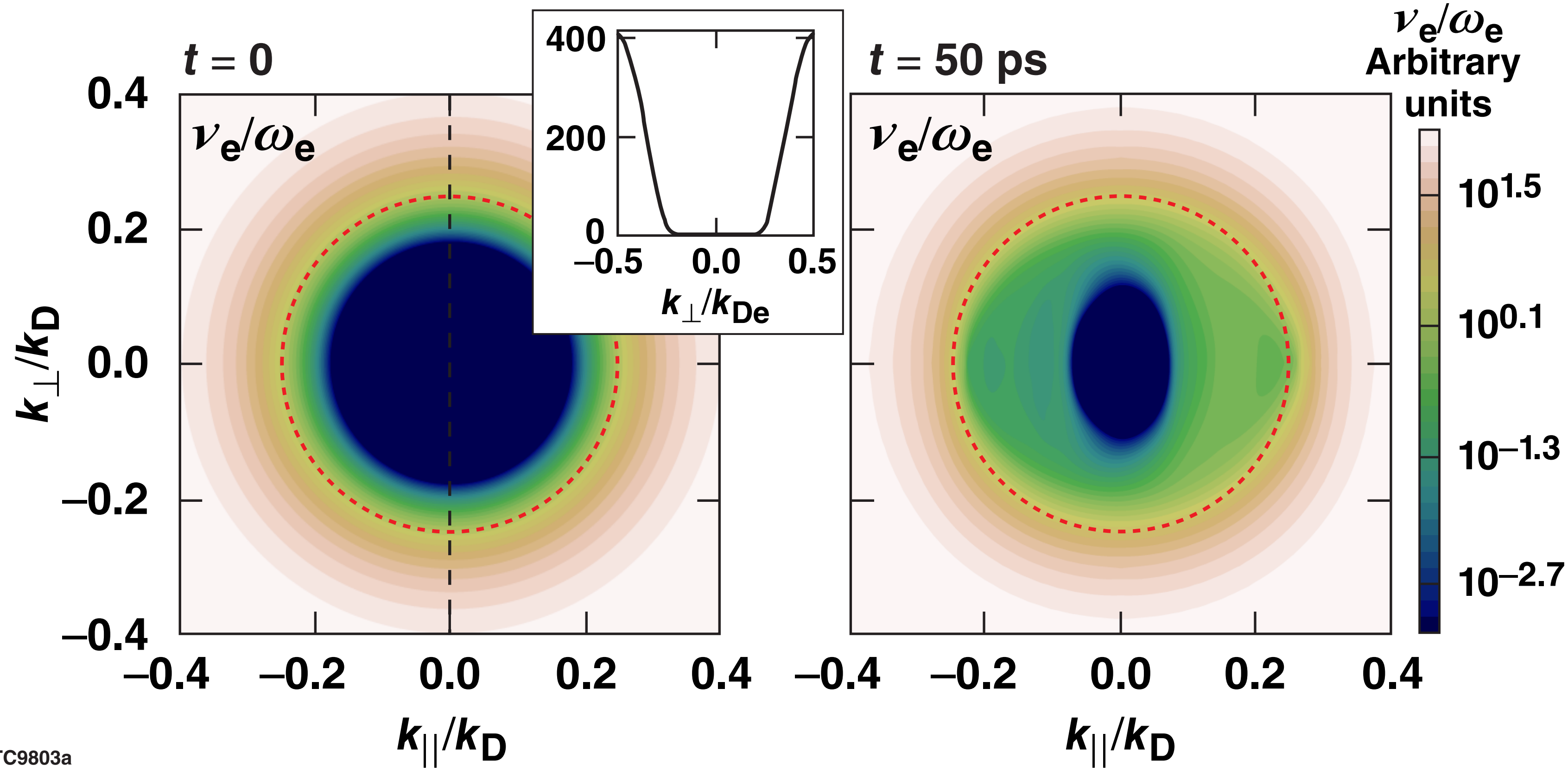
*D. A. Russell *et al*., "Two-Plasmon-Decay Turbulence Driven by the Shared-Wave Triad of Two Crossed Beams"; H. X. Vu *et al*., "Hot Electron Generation by 'Cavitating' Langmuir Turbulence in the Nonlinear Stage of the Two Plasmon Decay Instability," this conference.

TC9801a

The LW Landau damping rate $\nu_e(k)$ is recalculated based on the evolving distribution function

- The damping is the only mechanism where the particles act back on the waves

$$\nu_e(\vec{k},t) = \frac{\pi}{2}\frac{\omega_e^3}{k^2}\int d\vec{v}\,\frac{\vec{k}\cdot\partial\langle f_e(\vec{v},t)\rangle}{\partial\vec{v}}\,\delta(\omega_{pe}-\vec{k}\cdot\vec{v})$$



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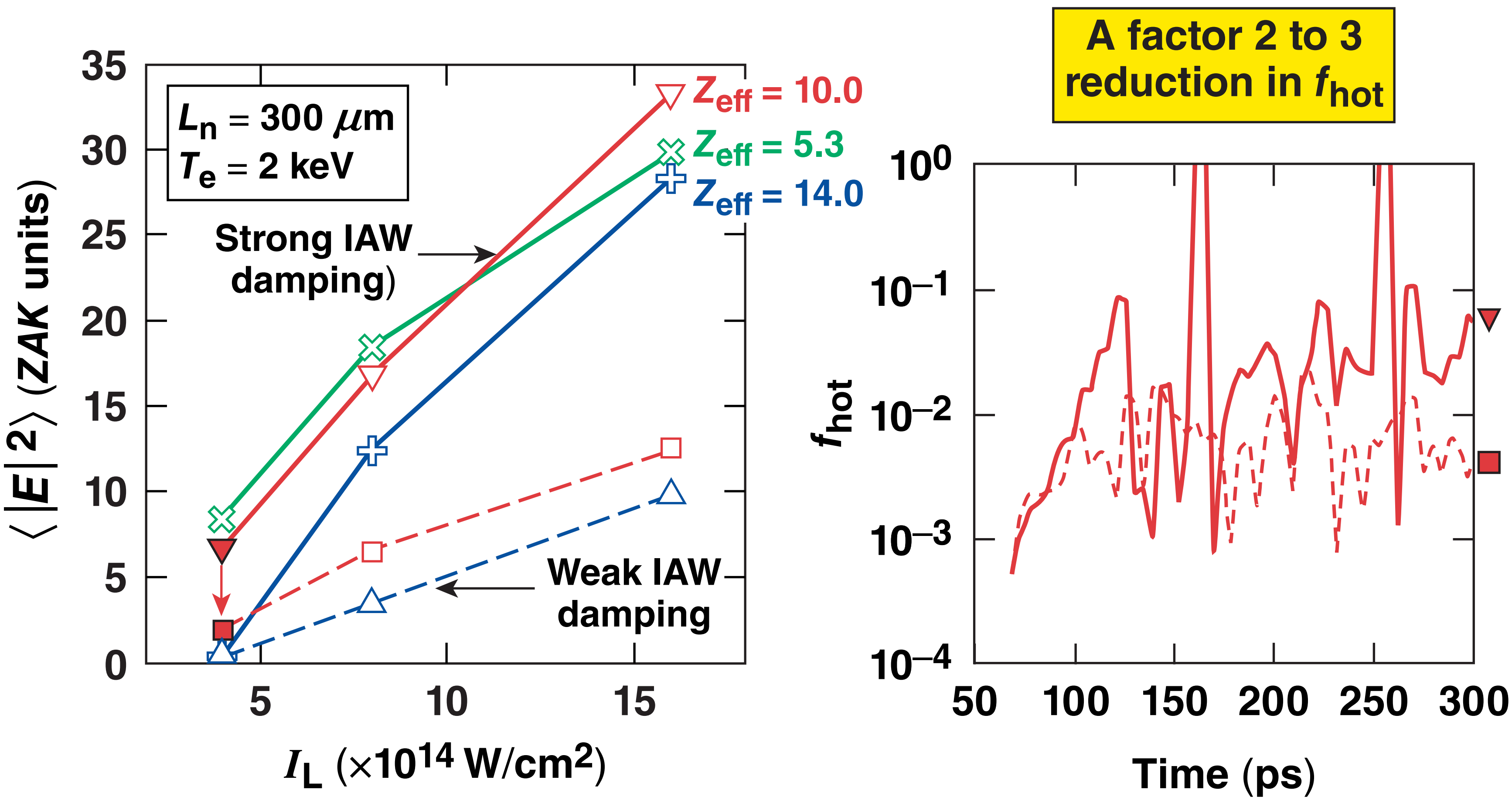
QZAK predicts less hot-electron production for a plasma with weakly damped ion-acoustic waves



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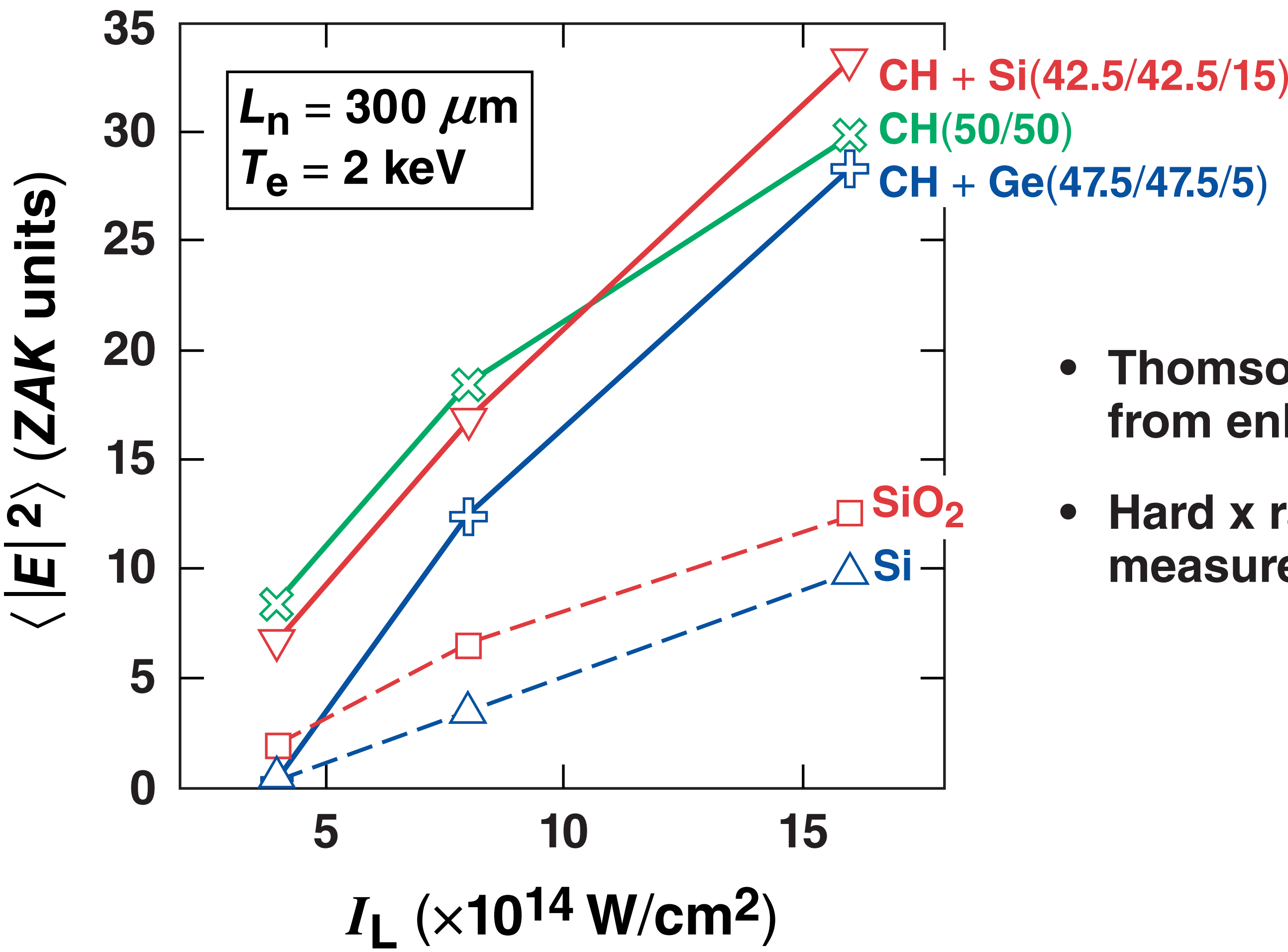
Ion-acoustic damping can be manipulated by modifying the plasma composition

- Ion Landau damping decreases with ZT_e / T_i ($c_s \gg v_{ti}$)
- Electron Landau damping in IAW's is always weak ($v_{te} \gg c_s$)
- Light ions (e.g., hydrogen) can increase the damping rate
- The multi-ion dispersion relation is solved by finding the most weakly damped mode*
- Ion–ion collisions complicate the matter
- Part of the spectrum will be collisionally damped because of ion viscosity ($k\lambda_{ii} < 10$)

*E. A. Williams *et al*., Phys. Plasmas 2, 129 (1995).

These effects can be investigated experimentally in planar targets on OMEGA/OMEGA EP†



- Thomson scattering from enhanced IAW*
- Hard x rays can be measured

† S. X. Hu *et al.*, "Analyses of Long-Scale-Length Plasma Experiments with Different Ablator Materials on the OMEGA EP Laser System," this conference.
* R. K. Follet *et al.*, "Thomson-Scattering Measurements of Ion-Acoustic Wave Amplitudes Driven by the Two-Plasmon Decay Instability," this conference.

TC10044

Summary/Conclusions

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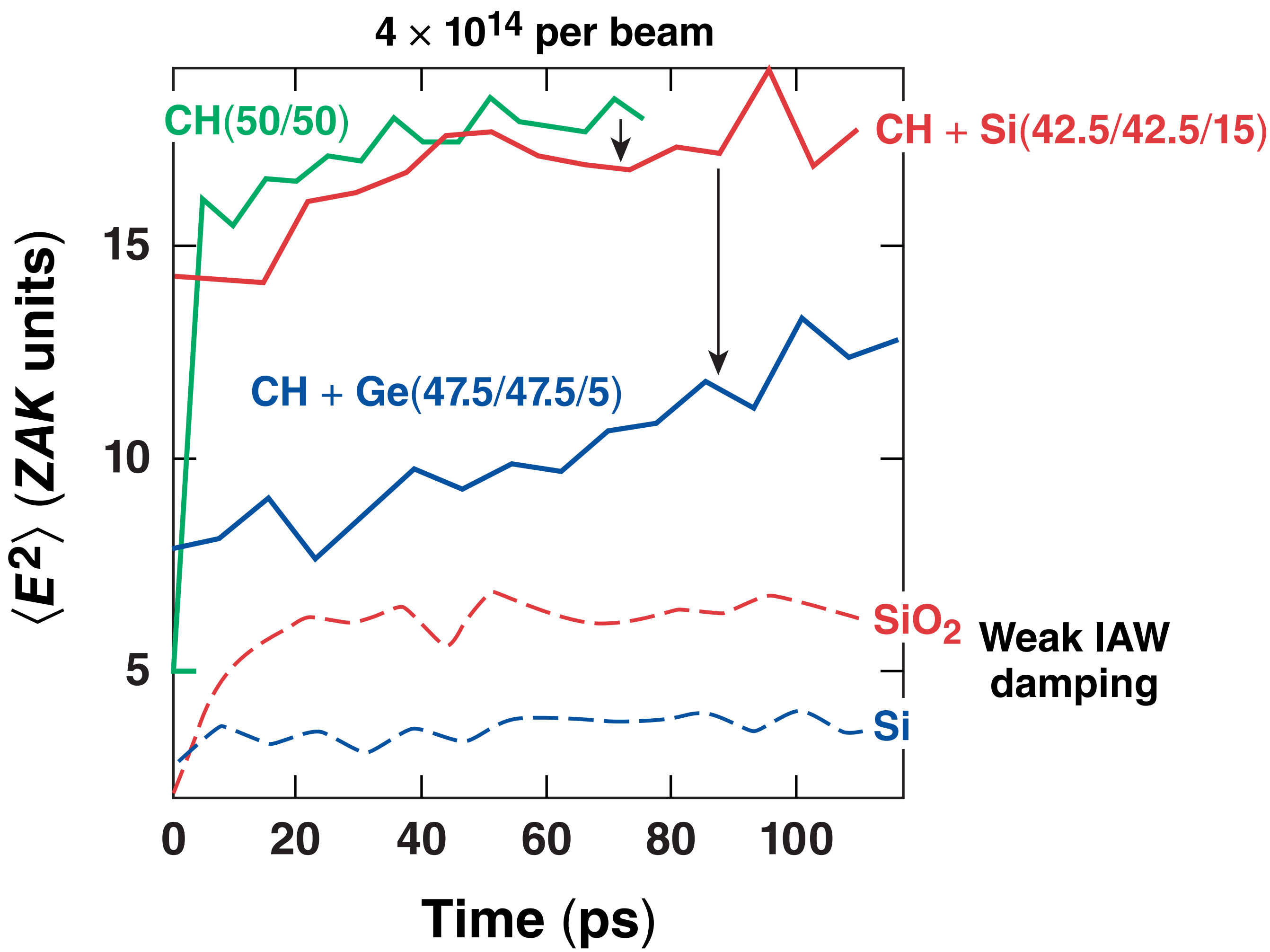
Time histories at mid-intensities



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