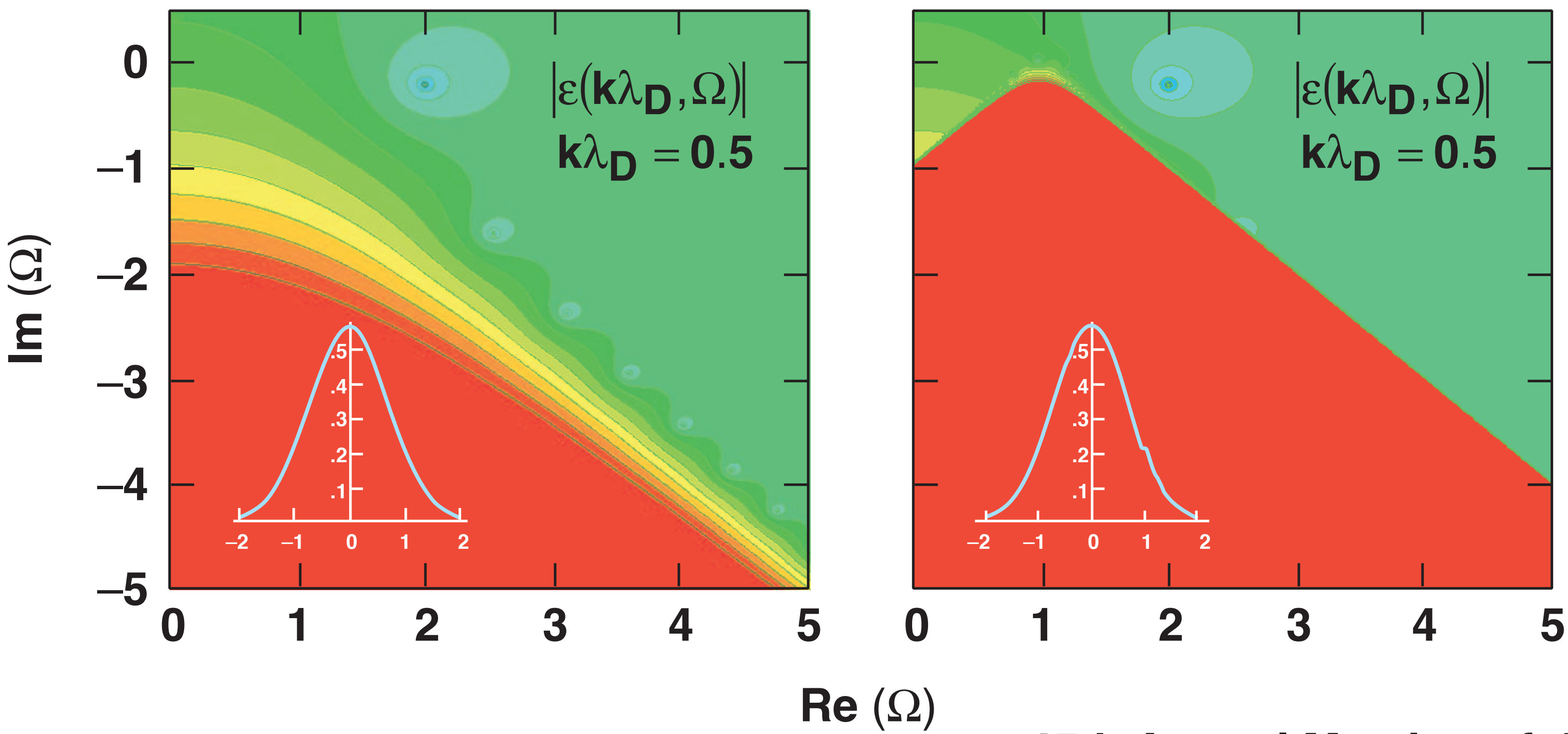
On the Role of Electron-Acoustic Waves in Two-Plasmon Decay and Stimulated Raman Scattering



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Summary

A model based on electron-acoustic waves can account for otherwise enigmatic features of both TPD and SRS

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- Why does the level of TPD activity depend on overlapped rather than single-beam intensities?
- Why does TPD respect the "Landau limit" on plasmon wave vector, while SRS does not?
- These observations imply the existence of plasma modes not described by the Bohm–Gross or Maxwellian Landau dispersion relations; electron acoustic waves provide this "missing link."

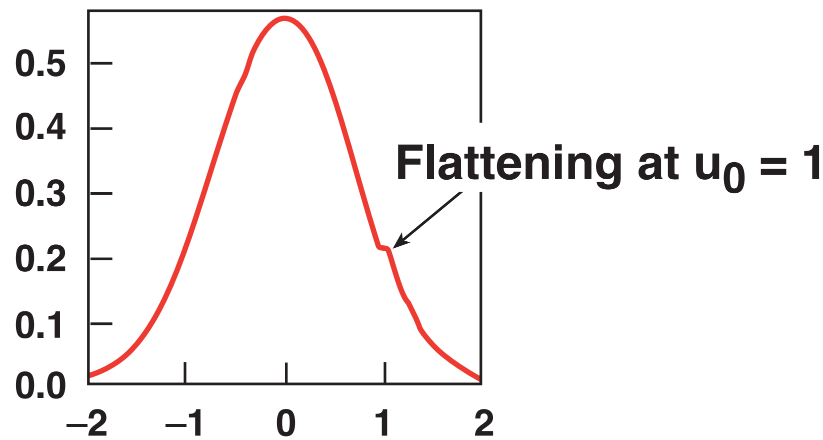
Outline

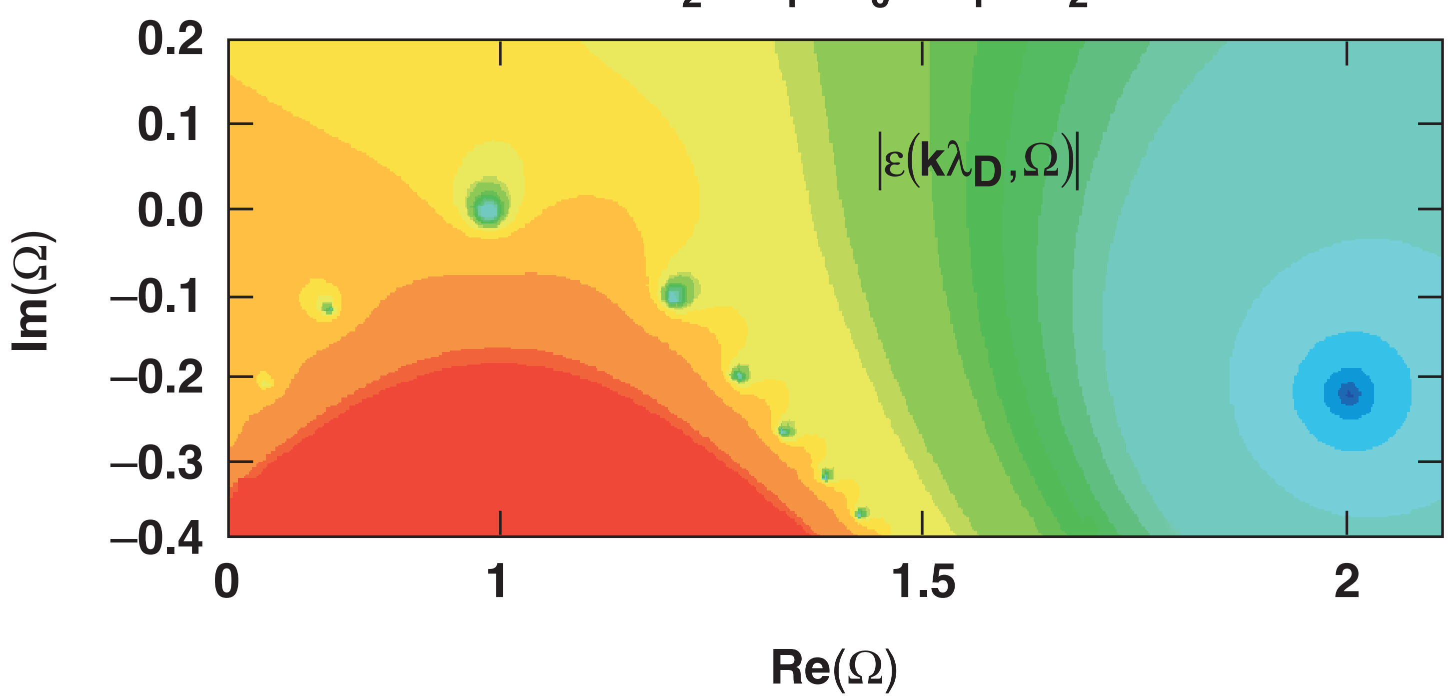
- Review of electron-acoustic (EA) waves and their relation to locally-flattened distribution functions.
- Role of local flattening in SRS compared to SEAS.
- Role of local flattening and EA waves in TPD.
- Summary and conclusions.

A localized flattening of the distribution function introduces a new linear family of modes

$k\lambda_D = 0.5$

$$\Omega \equiv \frac{\omega}{\sqrt{2}\,k v_T}$$





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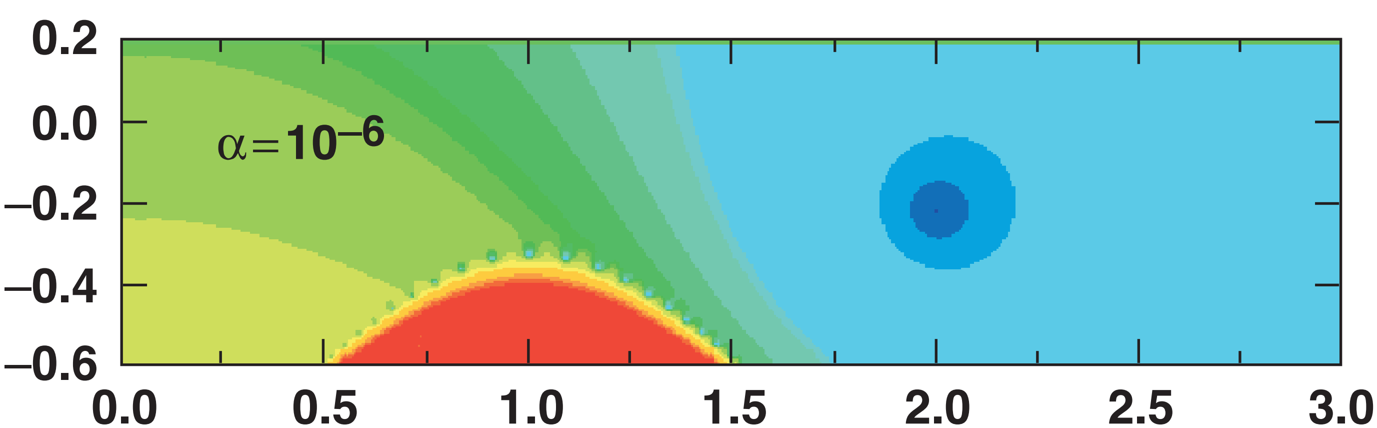
Even minuscule deviations from a Maxwellian introduce new moderately-damped modes

- **Local flattening is modeled by adding a localized term to a Maxwellian:**

$$f(u) = \frac{1}{\sqrt{\pi}} e^{-u^2} - \alpha f_0'(u_0)(u - u_0) e^{-\frac{(u-u_0)^2}{(\Delta u)^2}}; \ \alpha = 1 \text{ gives } f(u_0) = 0.$$

- $\mathrm{Re}[\varepsilon(\Omega = u_0, k\lambda_D)] = 0$ **is the dispersion relation for electron-acoustic waves, for** $\alpha = 1$ **these are undamped.**

- **Even at small values of the flattening parameter** α**, new moderately damped linear modes appear.**



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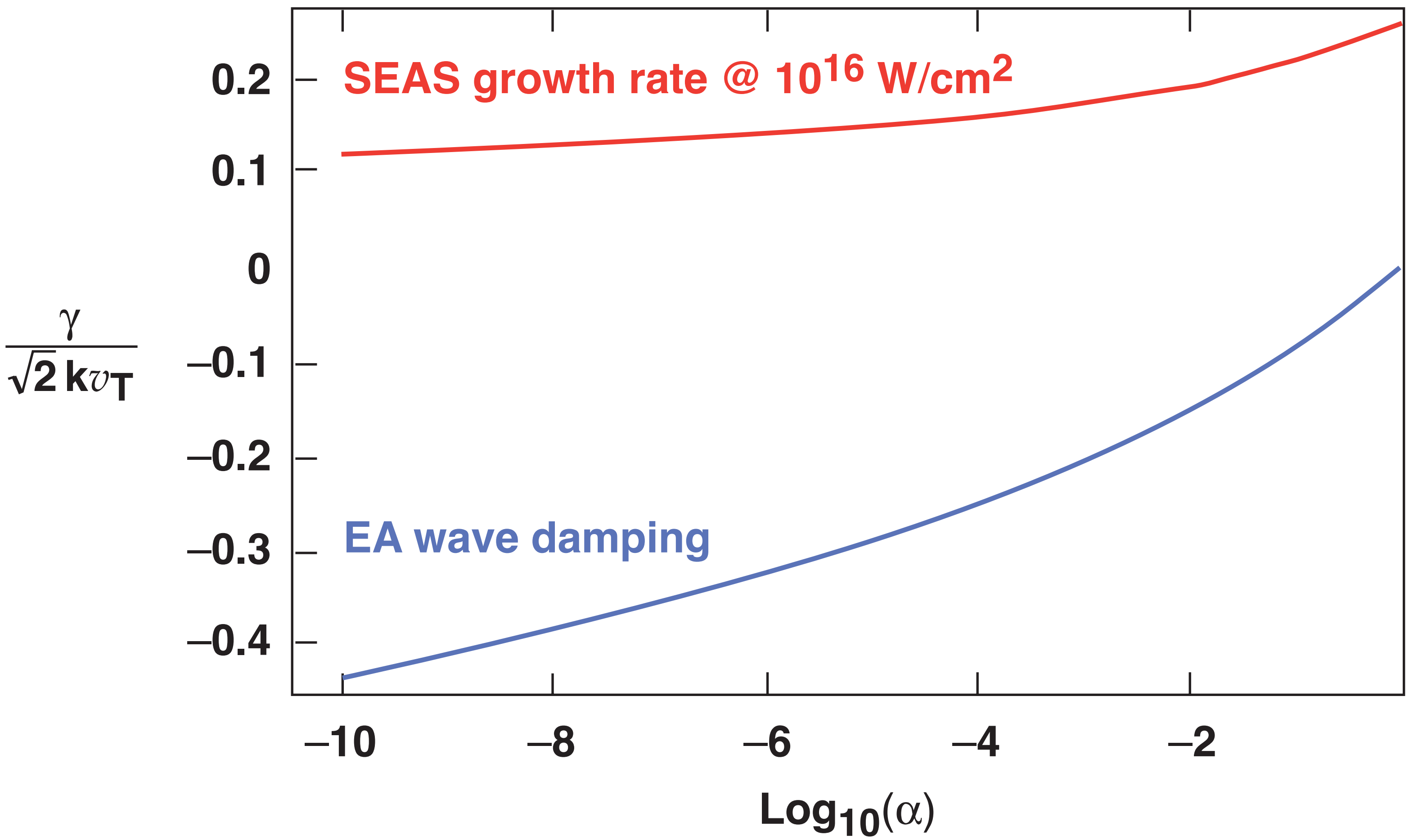
In SEAS, flattening develops from Landau damping of incoherent noise amplified by the pump

- Since the electromagnetic scattered wave has very low damping, the threshold for SEAS growth is exceeded even for small α.



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The evolution of the flattening is described by diffusion in velocity space

- Temporal evolution of the distribution function:

$$\frac{\partial f}{\partial t} = \frac{\partial}{\partial p_\alpha}\left(D_{\alpha\beta}\frac{\partial f}{\partial p_\beta}\right),$$

where $D_{\alpha\beta}(p) = 2\pi e^2 \int_{k \approx k_{res}} \left(E^2\right)_k \frac{k_\alpha k_\beta}{k^2}\,\delta(\omega - k \bullet \upsilon)\,\frac{d^3k}{(2\pi)^3}$

and $\left(E^2\right)_k$ is the power spectrum of linear EA waves.

- An initial slight flattening near the resonance for scattering results in growth of waves satisfying the matching condition, an enhanced diffusion coefficient, and further localized flattening.

- For small α, energy is transferred from the waves to f(u) at the Landau damping rate, and the flattening time is

$$\tau_{fl} \sim (\Delta u)^3 / \nu_L\,;$$

collisional diffusion tends to restore the Maxwellian on a timescale

$$\sim (\Delta u)^2 / \nu_{coll}\,.$$

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In the case of SRS, local flattening arises from damping of the amplified Landau mode

- SRS is often observed from plasma waves with large $k\lambda_D$. In a Maxwellian plasma, Landau damping would greatly reduce the growth of such modes.
- As in the SEAS case, incoherent noise with frequencies and wave vectors near the matching condition is amplified and results in local flattening and increased growth.
- Noise levels are larger near the Landau resonance, so SRS starts from a larger seed than SEAS; consequently, SRS levels are much larger.

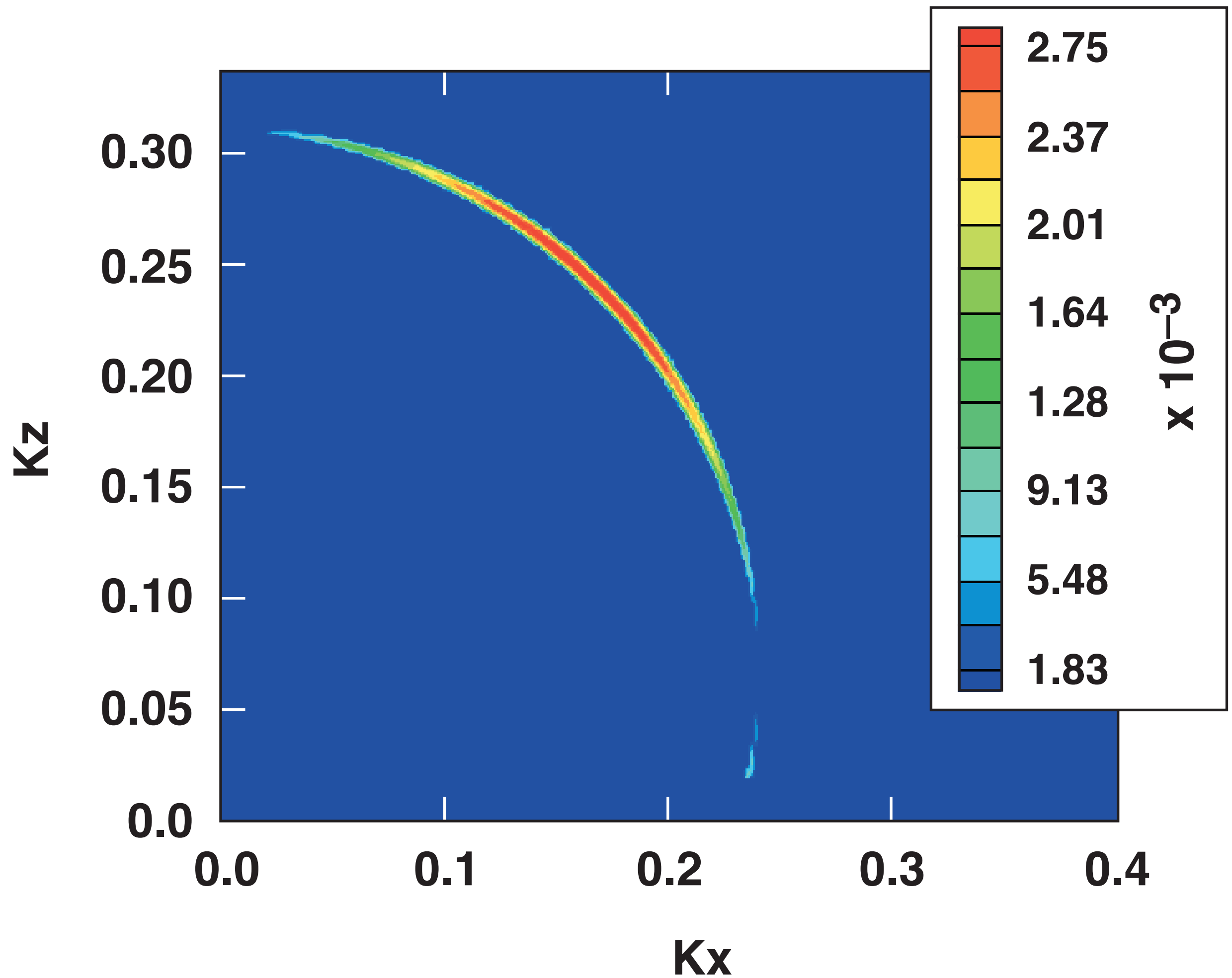
At moderate intensities, the range of plasmon wave vectors driven by TPD is narrow

- Growth rate γ/ω_p for single pump at 5×10^{14} W/cm^2

$n/n_c = 0.21$

$T_e = 2.5$ keV

$k_0\lambda_D \cong 0.12$



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Even at only 5° separation there is little enhancement of the single-beam growth rate

- Growth rate γ/ω_p for two pumps, each 5×10^{14} W/cm^2, separated by 5°.

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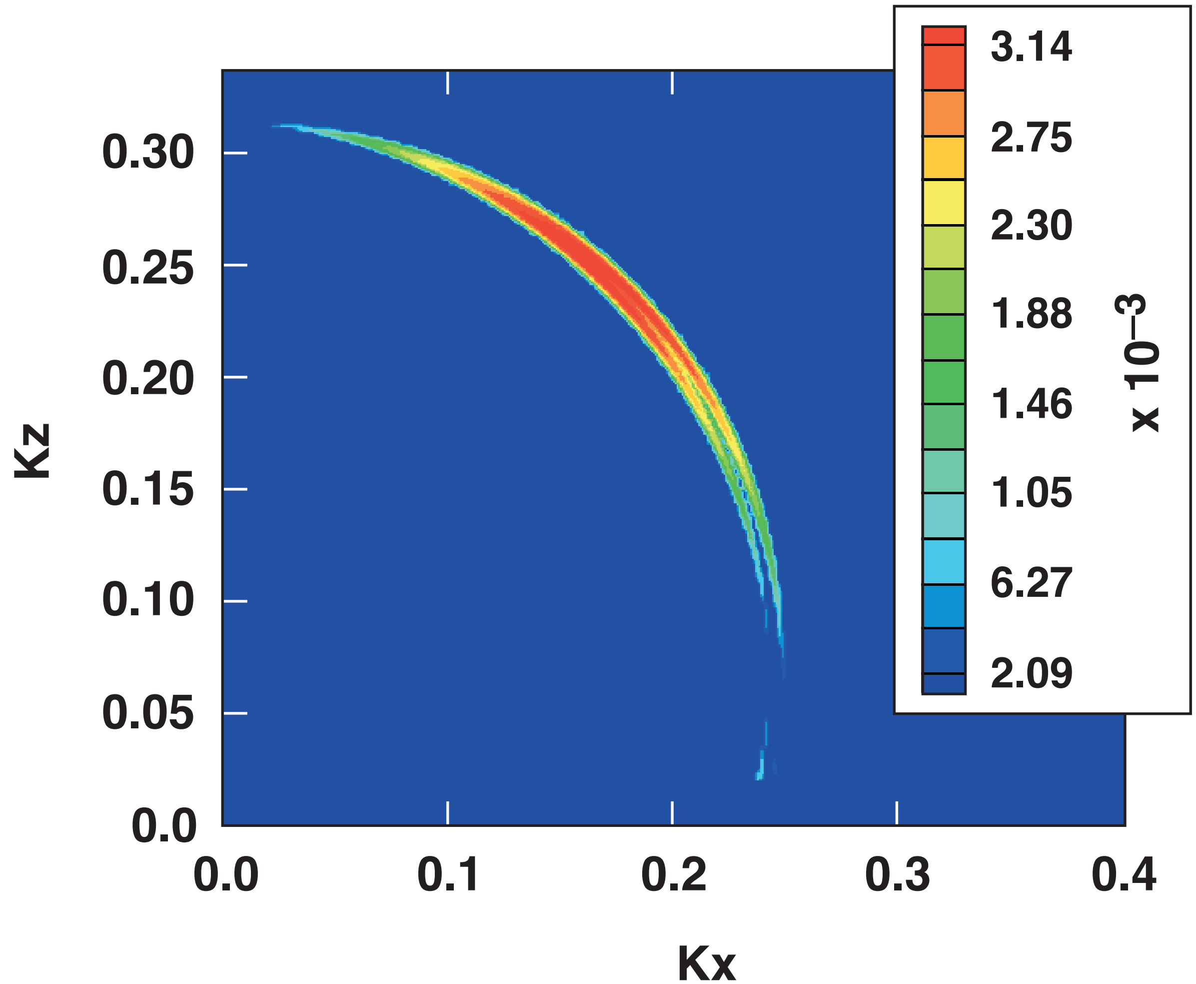
$T_e = 2.5$ keV

$k_0\lambda_D \cong 0.12$



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TPD is found to depend on overlapped beam intensities, and to be limited by the "Landau cutoff"

- The problem: if a pump $(\mathbf{k}_0, \omega_0)$ is resonantly coupled to a "signal" wave $(\mathbf{k}_1, \omega_1)$ by an "idler" wave $(\mathbf{k}_0 - \mathbf{k}_1, \omega_0 - \omega_1)$, then the idler wave $(\mathbf{k}_0' - \mathbf{k}_1, \omega_0 - \omega_1)$ required to link a second pump $(\mathbf{k}_0', \omega_0)$ to the signal $(\mathbf{k}_1, \omega_1)$ is not, in general, a normal mode of the plasma.

- But it can become one: the driven (ponderomotive) response at $(\mathbf{k}_0' - \mathbf{k}_1, \omega_0 - \omega_1)$ is subject to Landau damping, and hence locally flattens the distribution function of at the phase velocity

$$\frac{(\omega_0 - \omega_1)}{(\mathbf{k}_0' - \mathbf{k}_1)}.$$

- Local flattening introduces new, lightly-damped modes; these are (almost) electron acoustic modes. They provide the missing link.

Multiple-pump modes in LDF's can be studied by solving the kinetic dispersion relation

- The kinetic dispersion relation for two-pump TPD is

$$\frac{\varepsilon(\mathbf{k},\omega)}{1-\varepsilon(\mathbf{k},\omega)} = \frac{1-\varepsilon(\mathbf{k_0}-\mathbf{k},\omega_0-\omega)}{\varepsilon(\mathbf{k_0}-\mathbf{k},\omega_0-\omega)}\left\{\frac{(\mathbf{k}\bullet\mathbf{v_0})^2\left[(\mathbf{k_0}-\mathbf{k})^2-\mathbf{k}^2\right]^2}{4\omega_p^2\mathbf{k}^2(\mathbf{k_0}-\mathbf{k})^2}\right\}$$

$$+\frac{1-\varepsilon(\mathbf{k'_0}-\mathbf{k},\omega_0-\omega)}{\varepsilon(\mathbf{k'_0}-\mathbf{k},\omega_0-\omega)}\left\{\frac{(\mathbf{k}\bullet\mathbf{v'_0})^2\left[(\mathbf{k'_0}-\mathbf{k})^2-\mathbf{k}^2\right]^2}{4\omega_p^2\mathbf{k}^2(\mathbf{k'_0}-\mathbf{k})^2}\right\}.$$

- The local flattening makes $\varepsilon(\mathbf{k'_0}-\mathbf{k},\omega_0-\omega)$ resonant, so the second term contributes as much as the first.

How does TPD differ from anomalous (large $k\lambda_D$) SRS?

- In both cases the Landau damping of the beat of two lightly-damped modes (pump and signal) generates local flattening and a new, lightly damped mode (idler) that did not exist in the original Maxwellian.
- In the SRS case, both pump and signal are EM waves, essentially undamped for all k, so the idler can have large $k\lambda_D$.
- In the TPD case, the signal is a plasma wave and must have $k_1\lambda_D < 0.25$ to be lightly damped. Since $k_0\lambda_D \ll k_1\lambda_D$ at the Landau cutoff, we must also have $k_2\lambda_D \lesssim 0.25$.
- So TPD is limited by the Landau cutoff, while SRS is not.

Summary/Conclusions

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