Vlasov simulations of Raman scattering: kinetic enhancement and stimulated electron acoustic scatter

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Summary

1. ELVIS: 1-D Eulerian Vlasov-Maxwell solver developed and used.

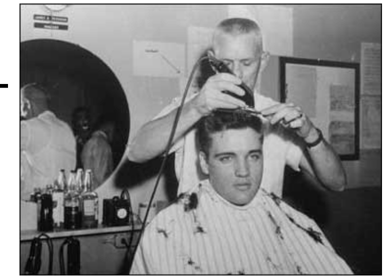
2. Kinetic enhancement of SRS: electron trapping reduces damping, shifts frequency.

3. Sharp onset of enhancement with parmeters like pump strength, electron temperature, and speckle sideloss rate.

4. Stimulated Electron Acoustic Scatter (SEAS) is observed after SRS is strong: light scattered off electron acoustic mode with trapping.

5. Conclusions and future work.

ELVIS: EuLerian Vlasov Integrator with Splines; 1-D Vlasov-Maxwell Solver



[D. J. Strozzi, M. M. Shoucri, A. Bers, Comp. Phys. Comm. **164**/1-3 (2004)]
[A. Ghizzo, P. Bertrand, M. M. Shoucri *et al.*, J. Comp. Phys. **90** (1990)]

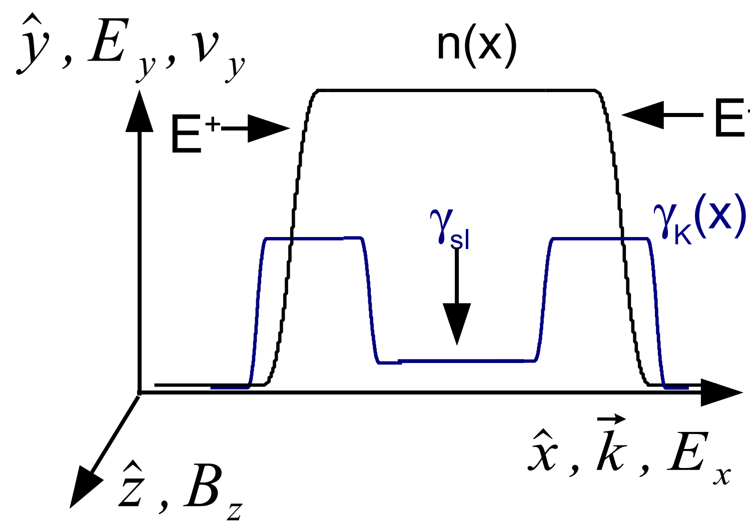
- Kinetic equation in *x*:

Krook operator

$$\frac{\partial f_s}{\partial t} + v\frac{\partial f_s}{\partial x} + q_s(E_x + v_y B_z)\frac{\partial f_s}{\partial p} = \gamma_K(x)(n_s \hat{f}_{0Ks} - f_s)$$

- Gauss' Law:

$$\partial_x E_x = e\epsilon_0^{-1}(Z_i n_i - n_e)$$



- Transverse motion: cold collisionless fluid

$$m_s \partial_t v_{ys} = q_s E_y$$

- Transverse Maxwell fields: linearly polarized in *y*

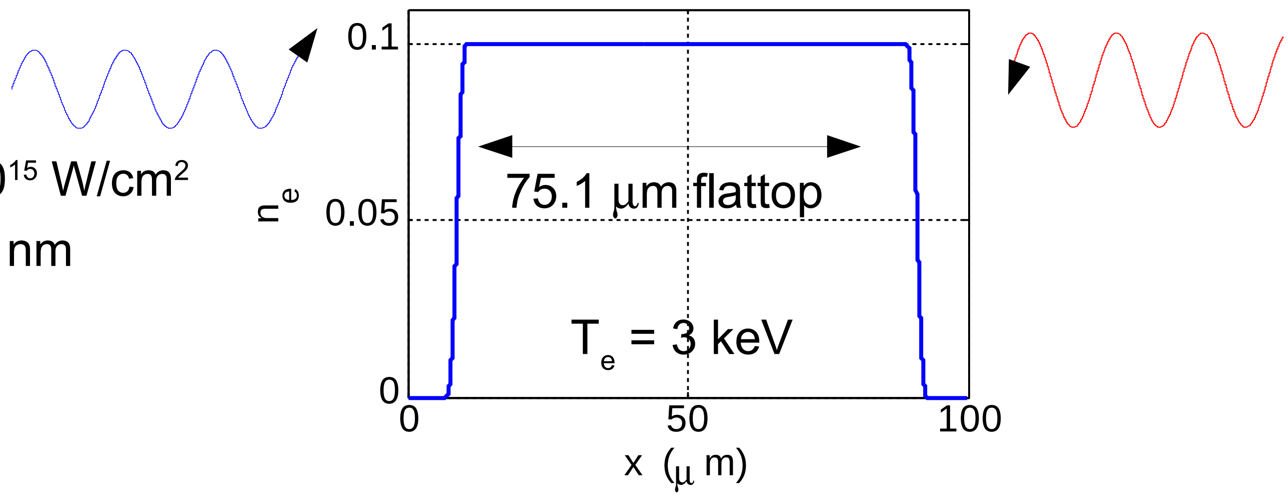
$$E^{\pm} \equiv E_y \pm c B_z \qquad (\partial_t \pm c\partial_x) E^{\pm} = -\epsilon_0^{-1} J_y \qquad E^{\pm} = \text{right, left moving}$$

Homogeneous plasma: SRS chaotic, well above linear gain

pump

$I_0 = 2\times10^{15}$ W/cm^2

$\lambda_0 = 351$ nm

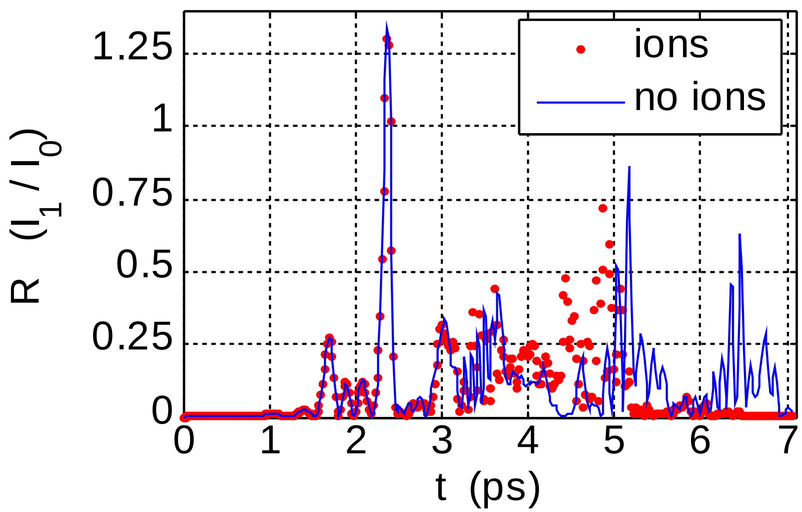


seed

$I_1 = 10^{-5}\, I_0$

$\lambda_1 = 574$ nm

Reflectivity at left edge
avg. (1-7 ps) = 13.9%



Ions: $ZT_e/T_i = 8$ (750 eV helium)

plasma wave:

$k_2\lambda_D = 0.357$

$\nu_2 = 0.031\omega_2$

coupled-mode theory:

$R = 0.0173\%$

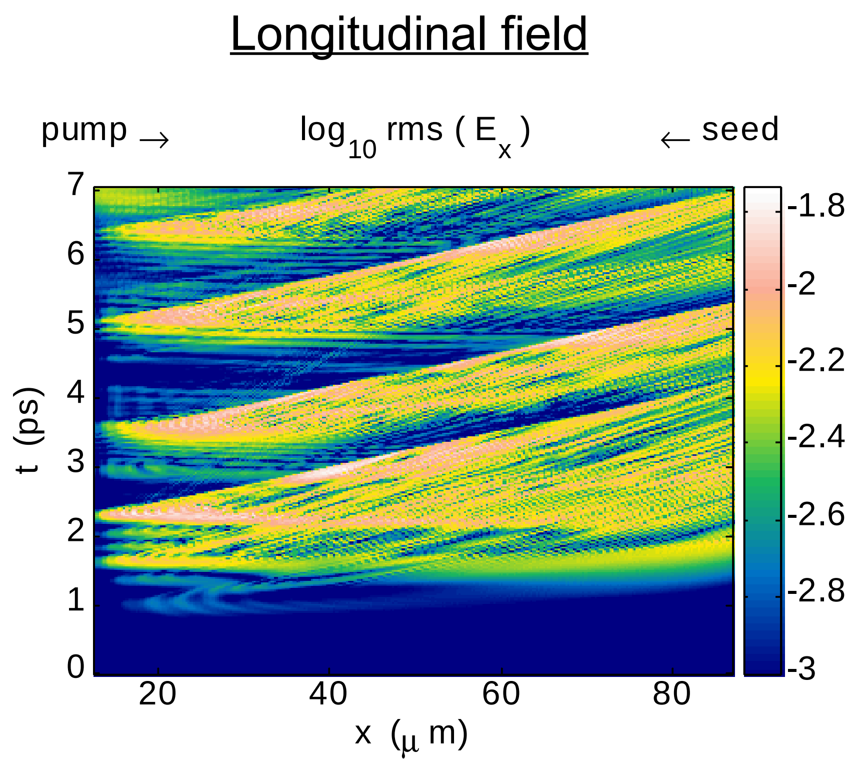
$\alpha^{-1} = 52.6$ μm

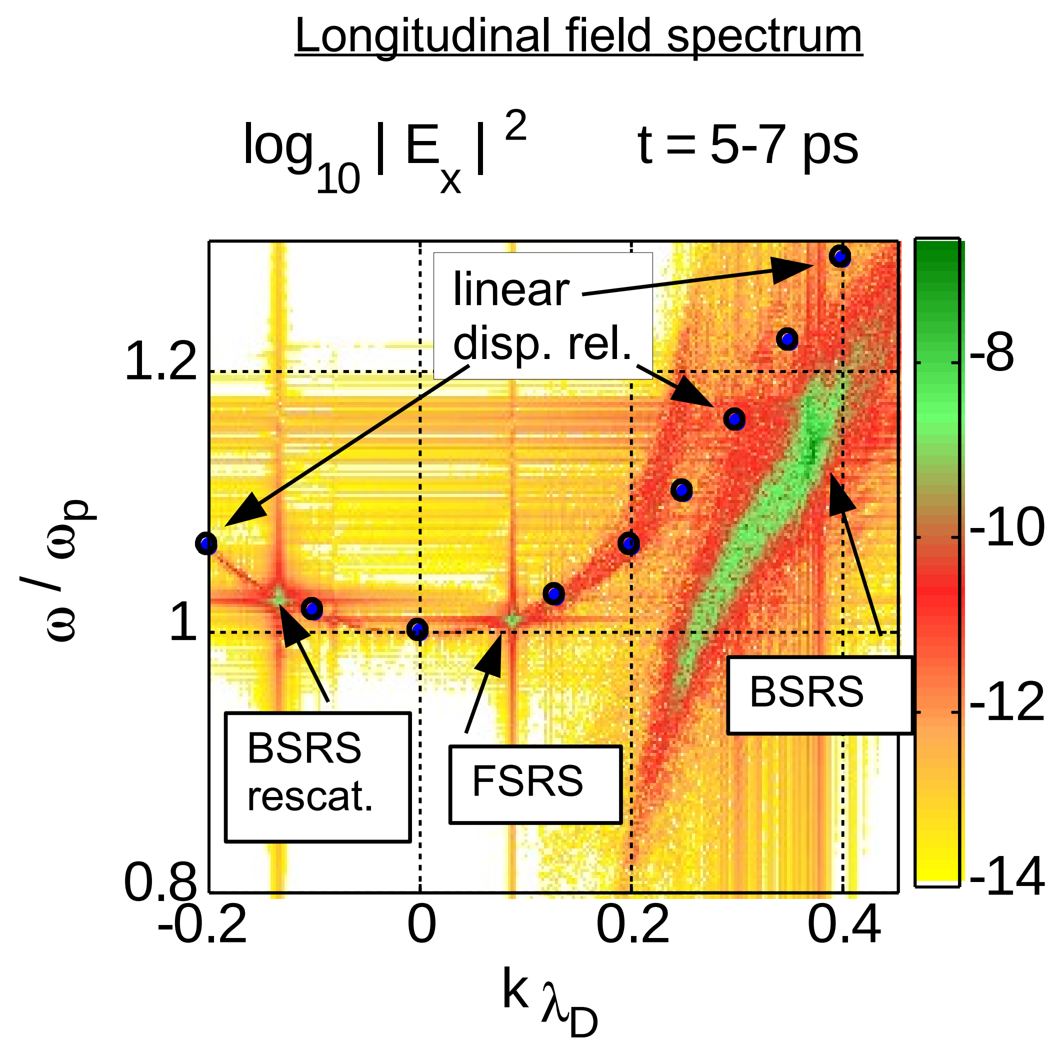
- SRS is bursty, chaotic, no steady state

[Vu et al., PRL 86 (2001); Phys. Plasmas 9 (2002);
Strozzi et al., J. Plasma Phys. 2005 (submitted);
D. J. Strozzi, PhD Thesis, 2005]

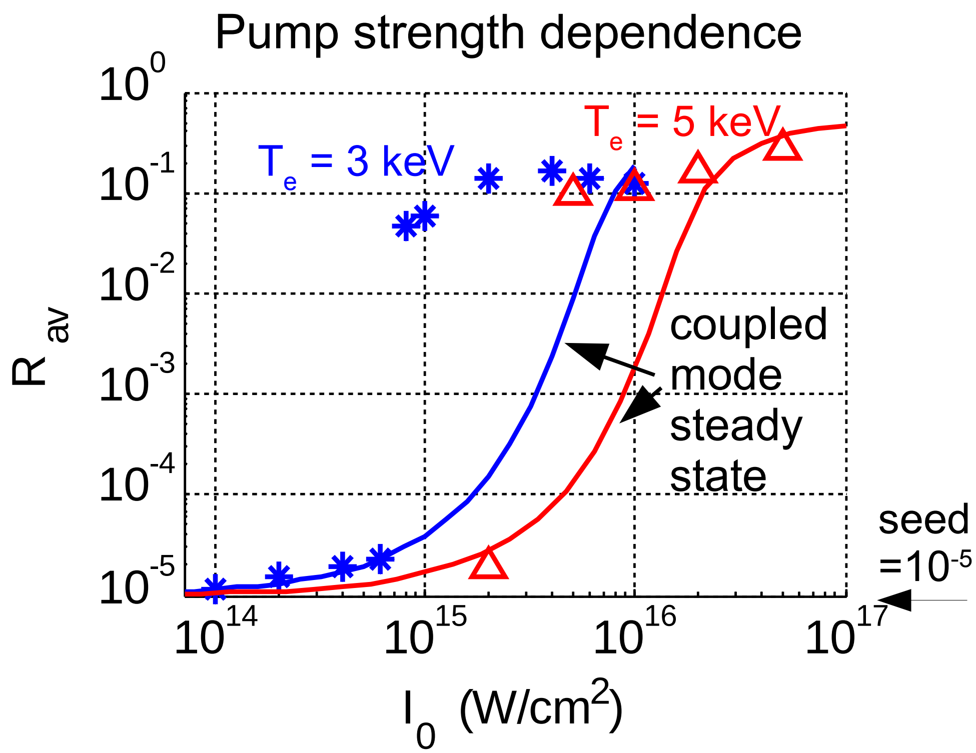
Movie of distribution function

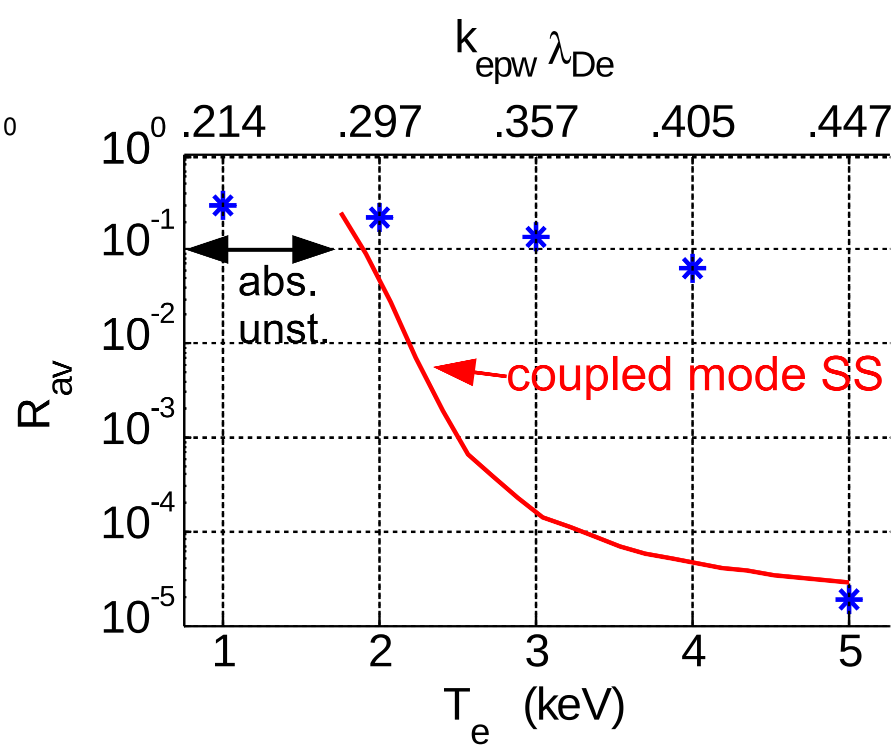
SRS plasma waves occur as series of right-moving pulses; trapping downshifts frequency from linear dispersion curve





Sharp threshold for kinetic enhancement with pump strength and T_e indicates trapping makes SRS absolute





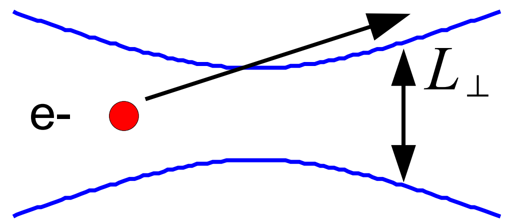
Speckle sideloss of electrons (2D effect) limits trapping when resonant electrons escape before bouncing

mimic sideloss in 1D

$$\frac{df}{dt} = \gamma_{sl}\left(n\hat{f}_0 - f\right) \qquad \text{Krook}$$

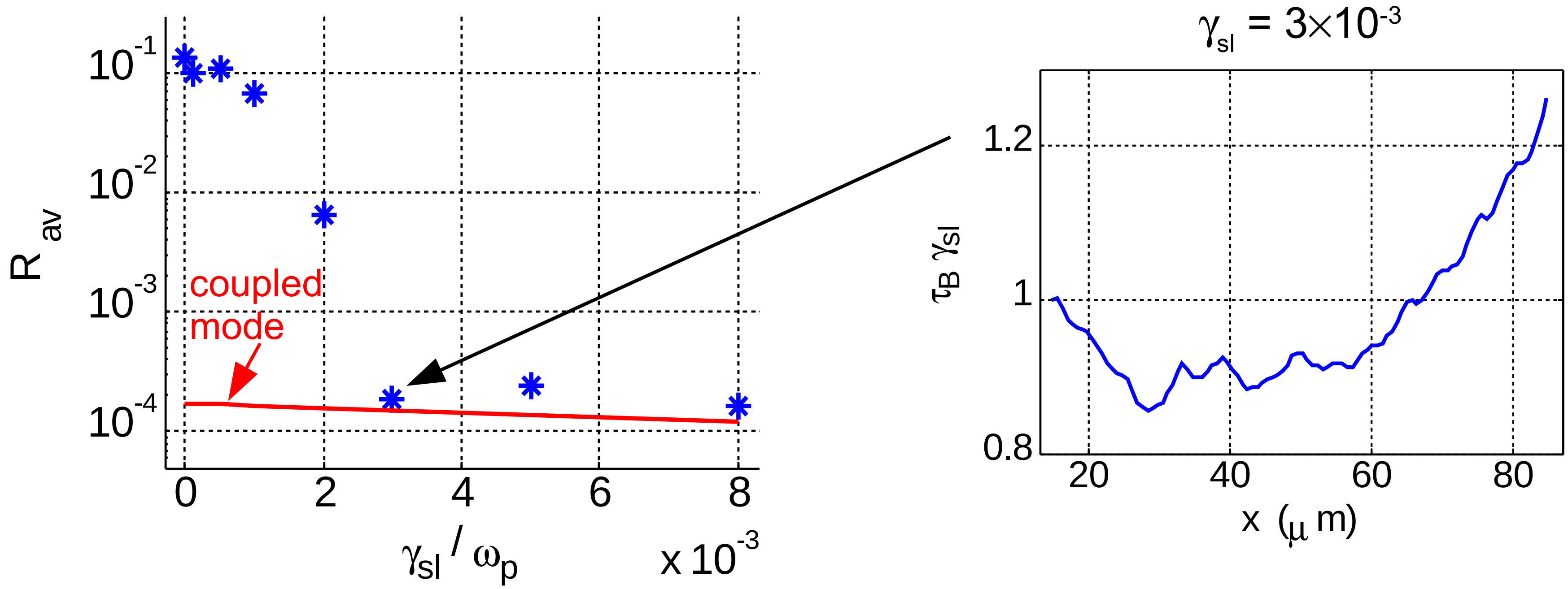
$$\gamma_{sl} = \frac{v_{Te}}{L_\perp} = \left(4.7\ \text{ps}^{-1}\right) T_{e,kV}^{1/2}\ \text{(NIF)}$$

diffraction-limited speckle



$$L_\perp = 1.028 F \lambda_0 = 2.81\ \mu\text{m}\ \ \text{(NIF)}$$

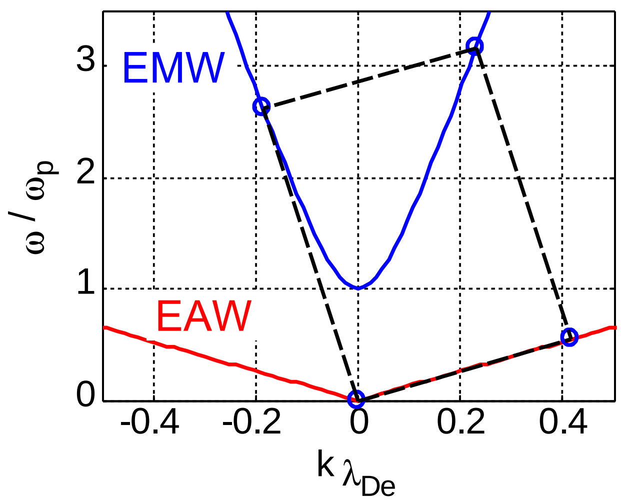
Sideloss rate dependence,
T_e = 3 keV, $I_0 = 2\times10^{15}$ W/cm^2

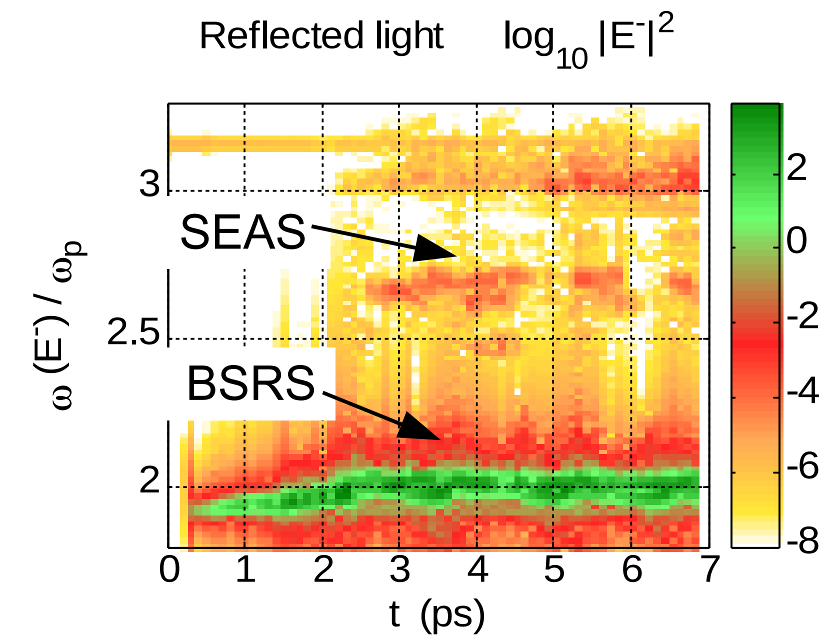


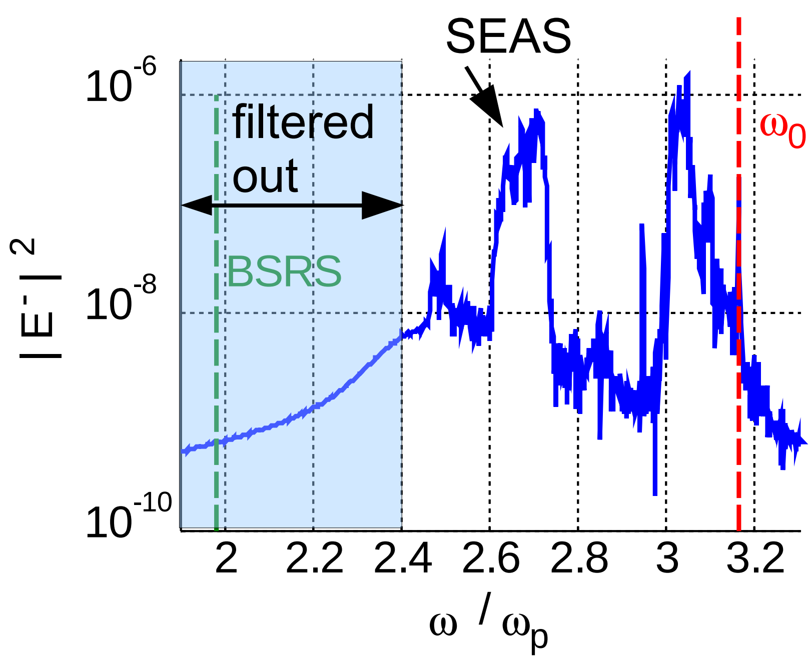
Stimulated Electron Acoustic Scatter (SEAS) is observed after SRS becomes large-amplitude

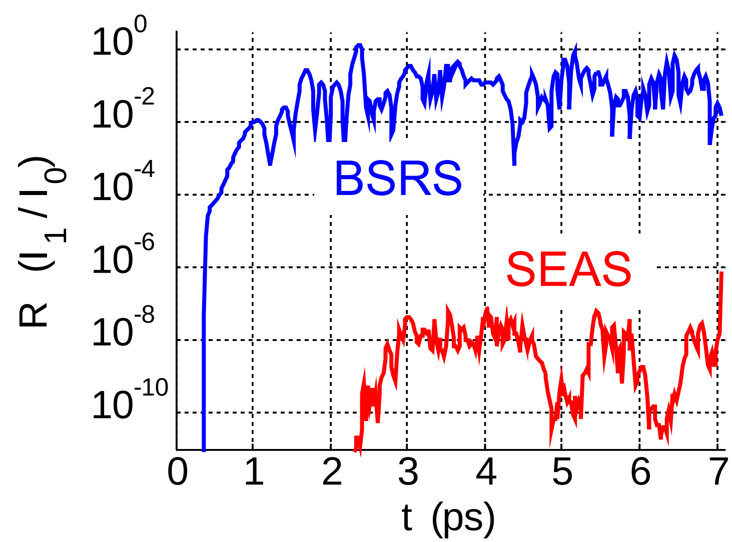
- SEAS: Scattering off electron acoustic waves ω ~ k

[R. J. Focia, PhD Thesis 2001; D. S. Montgomery et al, Phys. Rev. Lett. **87** (2001)]









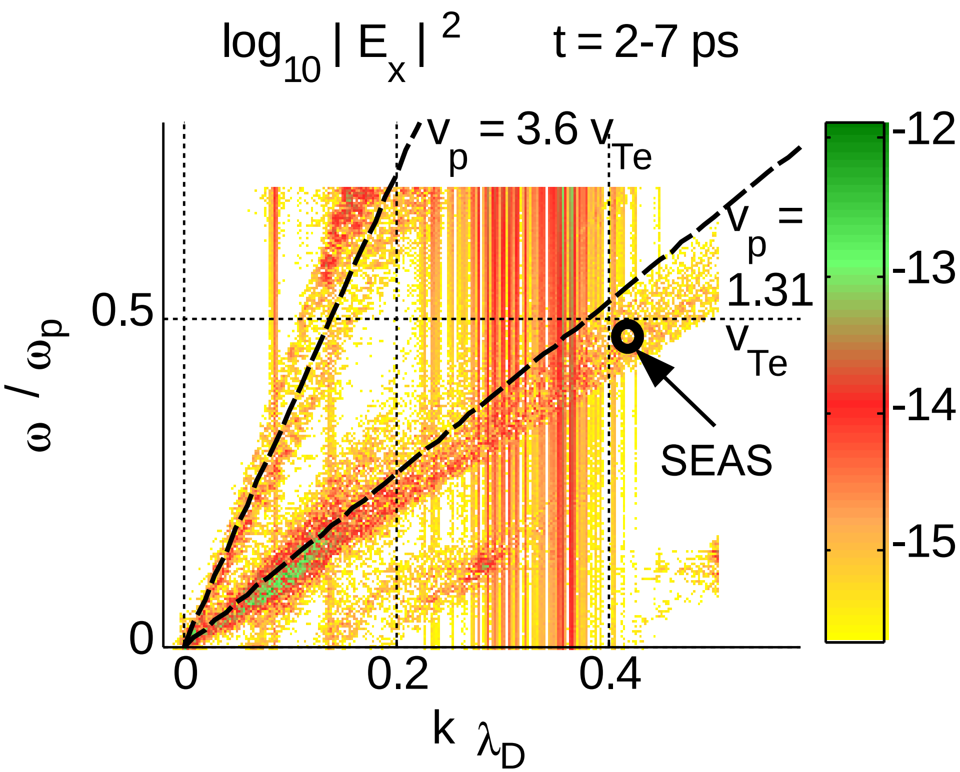
SEAS occurs from "ε_r=0" instead of natural modes; both are present in simulations. Indicates non-Maxwellian f_e.

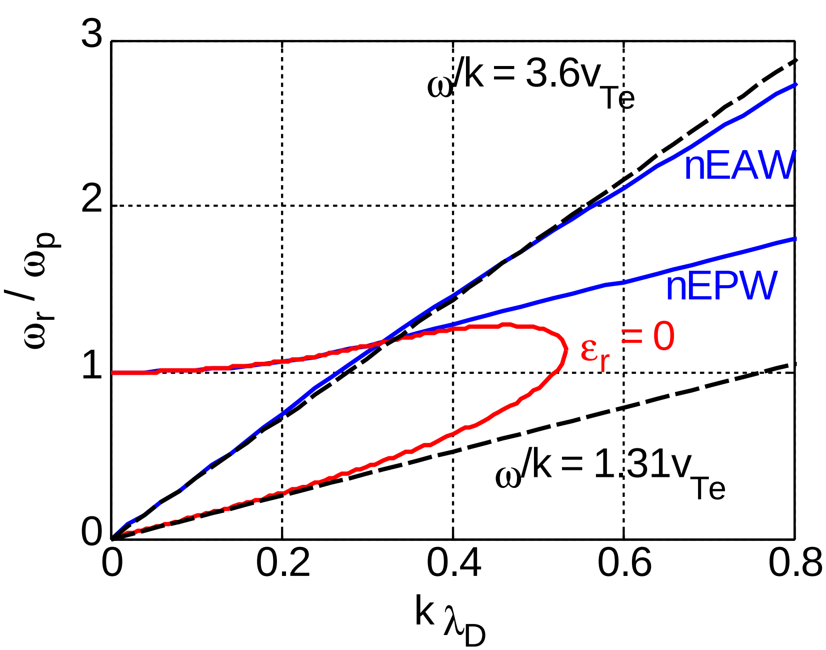
Linear permittivity: $\varepsilon(k,\omega) = 1 - \frac{1}{2k^2\lambda_D^2} Z'\left(\frac{\omega}{k v_{Te}\sqrt{2}}\right)$

"natural" (linear, Landau) modes: $\varepsilon(k,\omega) = 0 \quad \rightarrow \quad \omega_c(k_r)$ (damped)

"ε_r=0" (small-amplitude w/ trapping) modes: $\varepsilon_r(k,\omega) = 0 \quad \rightarrow \quad \omega_r(k_r)$

[Schamel, Phys. Plasmas **7** (2000); Rose and Russell, Phys. Plasmas **8** (2001)]





Conclusions

1. Electron trapping reduces Landau damping and kinetically enhances SRS.

2. Enhancement occurs suddenly as pump strength, T_e, and sideloss rate vary; agrees qualitatively with Trident experiments. Suggests SRS becomes absolute.

3. Stimulated electron acoustic scatter (SEAS) off the Schamel-Rose acoustic mode develops once SRS is strong. This indicates significant non-Maxwellian features.

Future work

1. Better understand when enhancement occurs, theory for time-averaged reflectivity.

2. SEAS: What conditions favor SEAS? Linear analysis of modes for numerical distribution from SRS simulation: what acoustic modes are present?

3. Inhomogeneous plasma: promised in abstract, coming soon (see D. J. Strozzi, PhD thesis, 2005)...