Observation of Two-Plasmon–Decay Common Plasma Waves Using UV Thomson Scattering

Common-wave Thomson-scattering spectrum
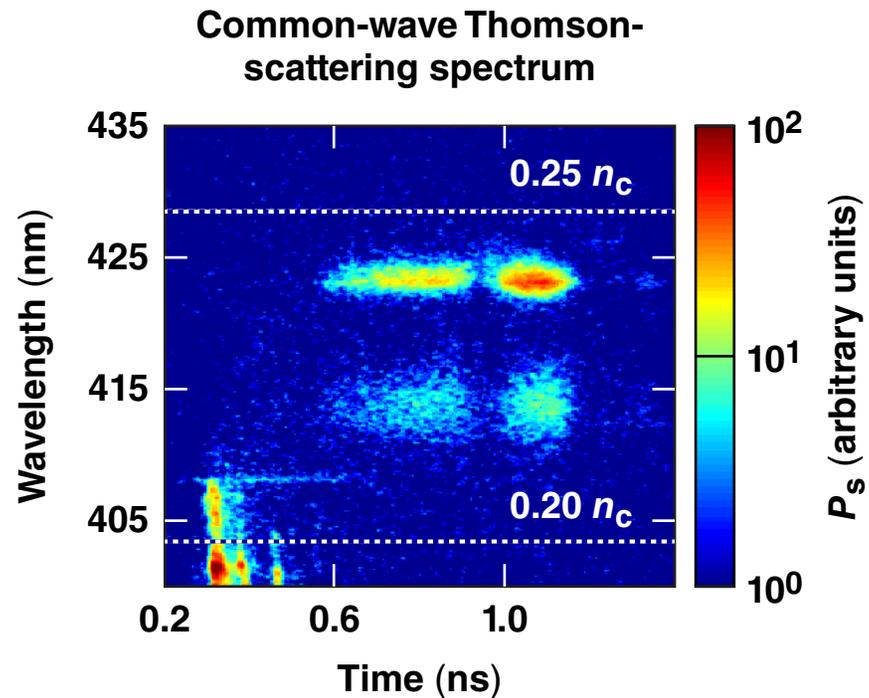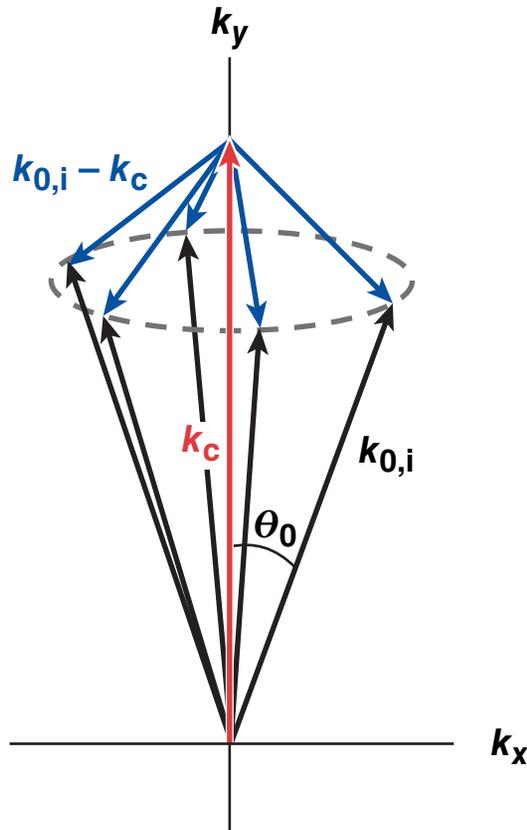
R. K. Follett
University of Rochester
Laboratory for Laser Energetics

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Summary

Electron plasma waves (EPW's) driven by common-wave two-plasmon decay (TPD) were observed on OMEGA using UV Thomson scattering

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- TPD-driven EPW's driven by five OMEGA beams at 23° to target normal were observed in two different scattering geometries

- A narrow spectral feature, consistent with scattering from waves driven on the TPD maximum-growth hyperbola, was observed when probing the common EPW

  - a second scattering feature was observed at a frequency consistent with Langmuir decay of TPD-backscattered EPW's

- Broad TPD-driven spectral features were observed when probing k vectors off of the maximum growth hyperbola, consistent with TPD k-space saturation

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Collaborators

D. H. Edgell, R. J. Henchen, S. X. Hu, D. T. Michel, J. F. Myatt, H. Wen, and D. H. Froula

University of Rochester
Laboratory for Laser Energetics

Multiple beams can drive a common electron plasma wave when they share the same relative angle

TPD k matching on maximum growth hyperbola

$$k_\perp^2 = k_\parallel (k_\parallel - k_0)$$

$k_\parallel$

k_2
(backscattered)

k_1
(forward scattered)

k_0

$k_\perp$

Five-beam common-wave k matching*

k_y

$k_{0,i} - k_c$

k_c

$k_{0,i}$

θ_0

k_x

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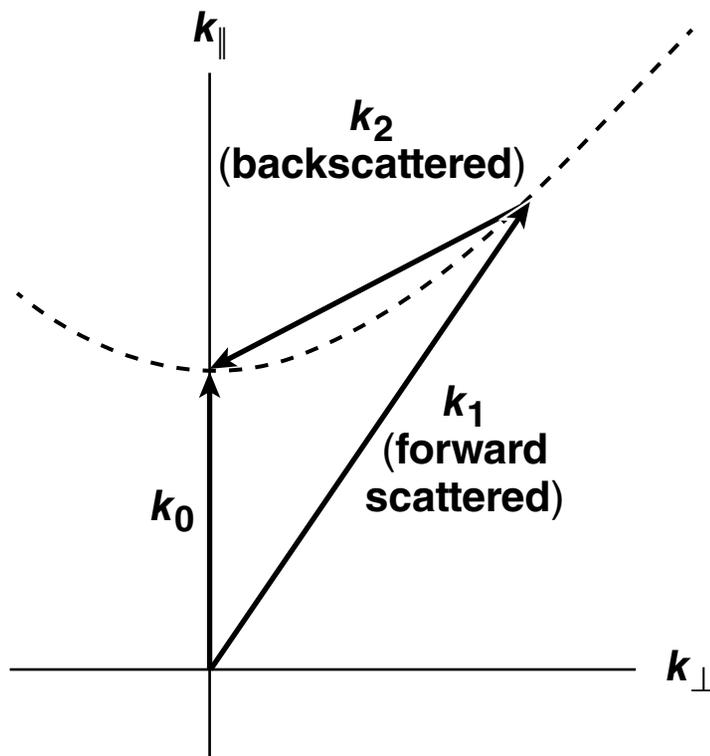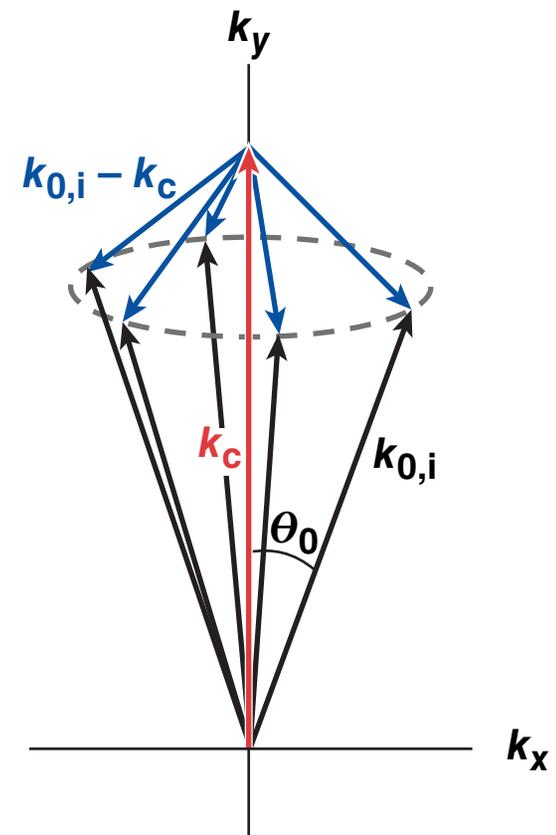
Simulations have shown *k*-space saturation in the nonlinear stage of two-plasmon decay*

Linear regime (two 23° beams) $|E_L|^2$

Landau cutoff
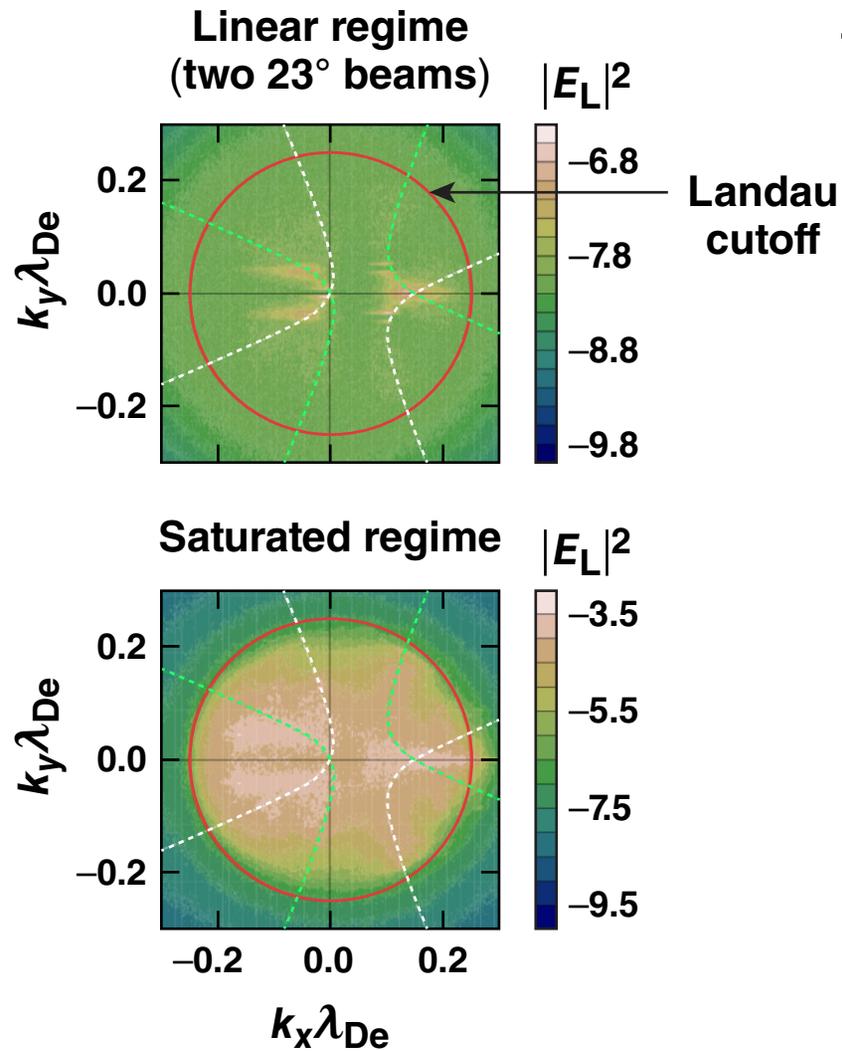
The Langmuir decay instability (LDI) has been associated with TPD saturation**

$$k'_{EPW} = k_{EPW} + k_{IAW: \text{ion-acoustic wave}}}$$

k'_{EPW}

k_{IAW}

k_{EPW}

Saturated regime $|E_L|^2$

$k_x\lambda_{De}$
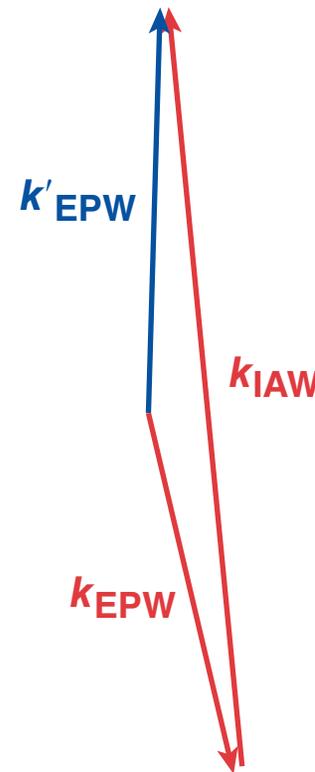
*H. X. Vu *et al*., Phys. Plasmas 17, 072701 (2010)
**J. F. Myatt *et al*., Phys. Plasmas 20, 052705 (2013).

Thomson scattering (TS) was used to observe the common electron plasma wave driven by five OMEGA beams

Experimental configuration

Five-beam common-wave k matching in TS plane

$300~\mu m$

CH target

Thomson-scattering volume
$(50 \times 50 \times 50~\mu m)$

k_S

k_T (263-nm probe)

$k_{0,i}$

k_C

k_y

$k_{0,i} - k_C$

k_C

k_T

$k_{0,i}$

k_S

k_x

f/10 collection to spectrometer and streak camera

Five 3ω (351-nm) drive beams (1.5 kJ, 1 ns or 2 ns)
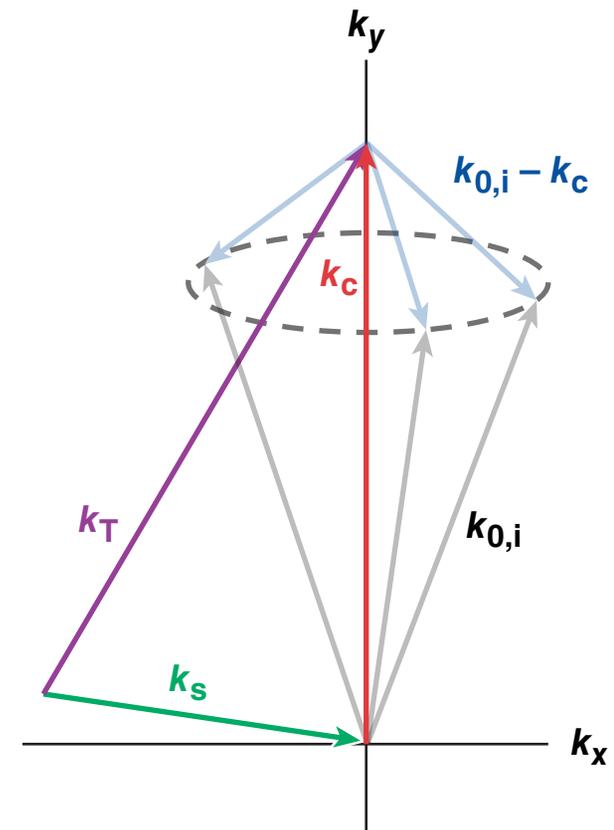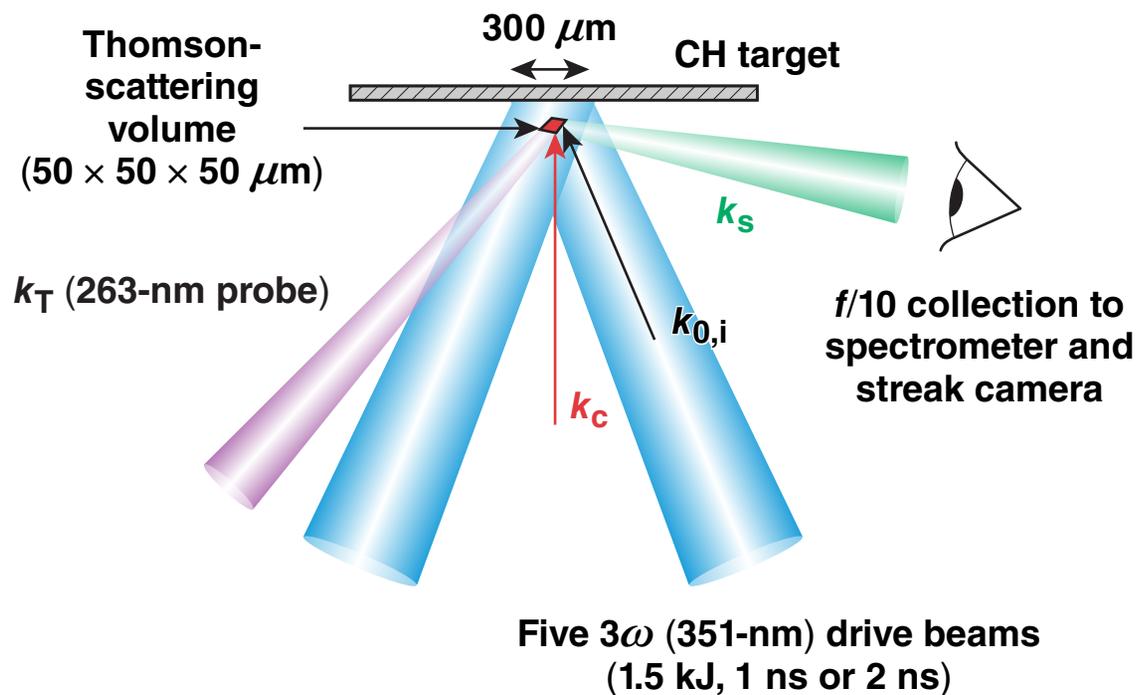
The Thomson-scattering volume was moved to observe different density regions.

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Thomson scattering probes a finite region of both physical and *k* space

$$\omega_s \cong \omega_T - \omega_p - \frac{3}{2}\frac{k^2 v_{th}^2}{\omega_p}$$

$\uparrow$ $\uparrow$

$\Delta\omega_s$ Δn_e

Range of observed densities in Thomson-scattering volume

Common-wave TS region

Thermal TS region

$n_c/4$

$n_c/5$

410 nm

390 nm

n_e/n_c

Distance from target surface (μm)

Thermal Thomson-scattering spectrum

0.25 n_c

0.20 n_c

Wavelength (nm)

Time (ns)

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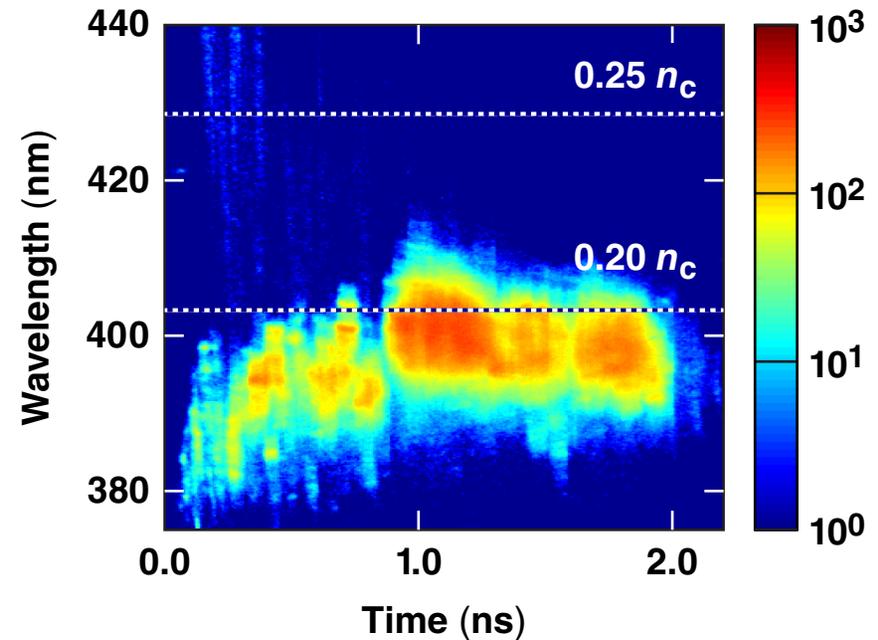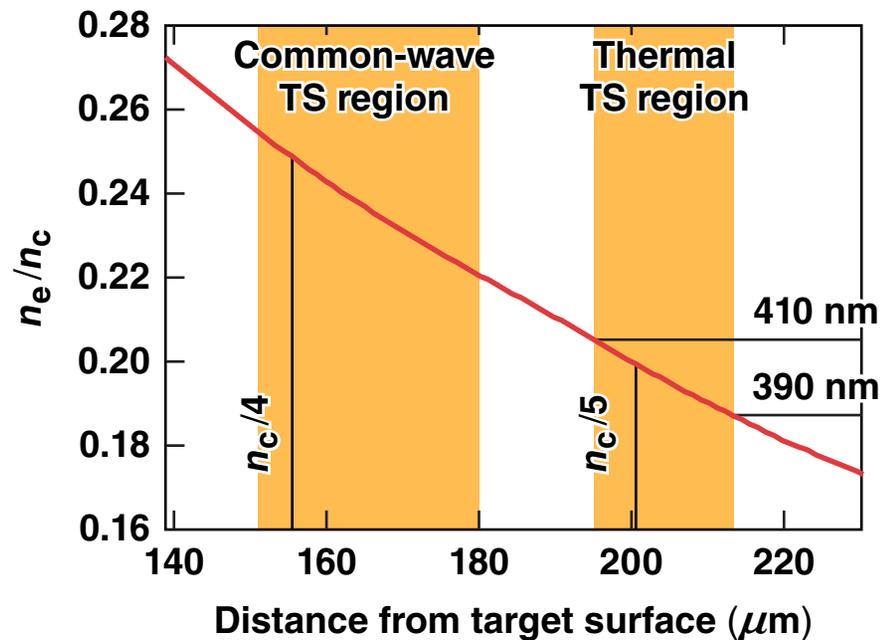
The range of densities where TPD-driven waves are observed is limited by the range of *k* space probed by Thomson scattering

TPD maximum growth hyperbola and dispersion/matching equations $\longrightarrow$ $\dfrac{n_e}{n_c} \approx \dfrac{1}{4}\left[1 - \dfrac{9}{4}\dfrac{v_{te}^2}{c^2}\left(1 + 4\dfrac{k_1^2}{k_0^2} - \sqrt{8\dfrac{k_1^2}{k_0^2} + 1}\right)\right]$

Range of observed densities in Thomson-scattering volume

Observable density range for TPD-driven EPW's
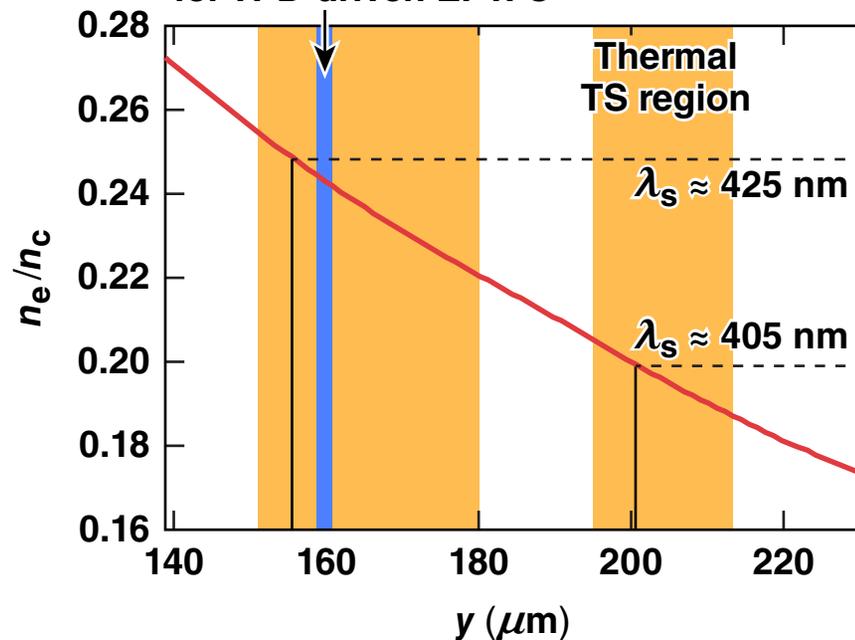
Five-beam common-wave growth rate* in Thomson-scattering plane

Linear growth rate ($\times 10^{12}$ 1/s)

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*D. T. Michel *et al.*, Phys. Plasmas <u>20</u>, 055703 (2013).

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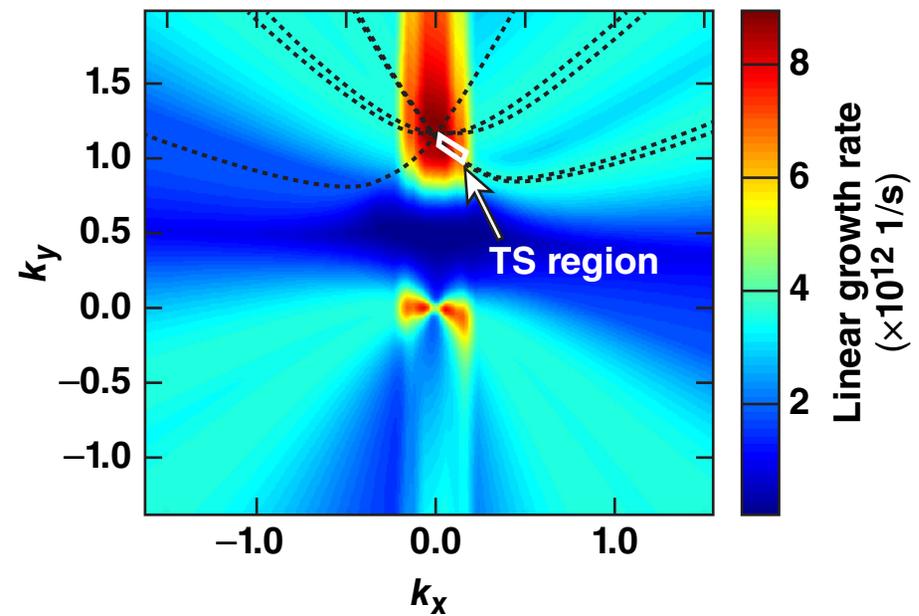
A narrow TPD-driven feature is observed in the common-wave scattering geometry consistent with the limited density range defined by TPD

Common-wave TPD Thomson-scattering spectrum

Thermal Thomson-scattering spectrum

Thermal Thomson-scattering spectral lineouts (1 ns)

- Thermal: $\omega_s = \omega_T - \omega (n_e, k)$
- TPD driven: $\omega_s = \omega_T - \omega (k)$

$k_1 = k_c$ (primary)

k'_2 (LDI)
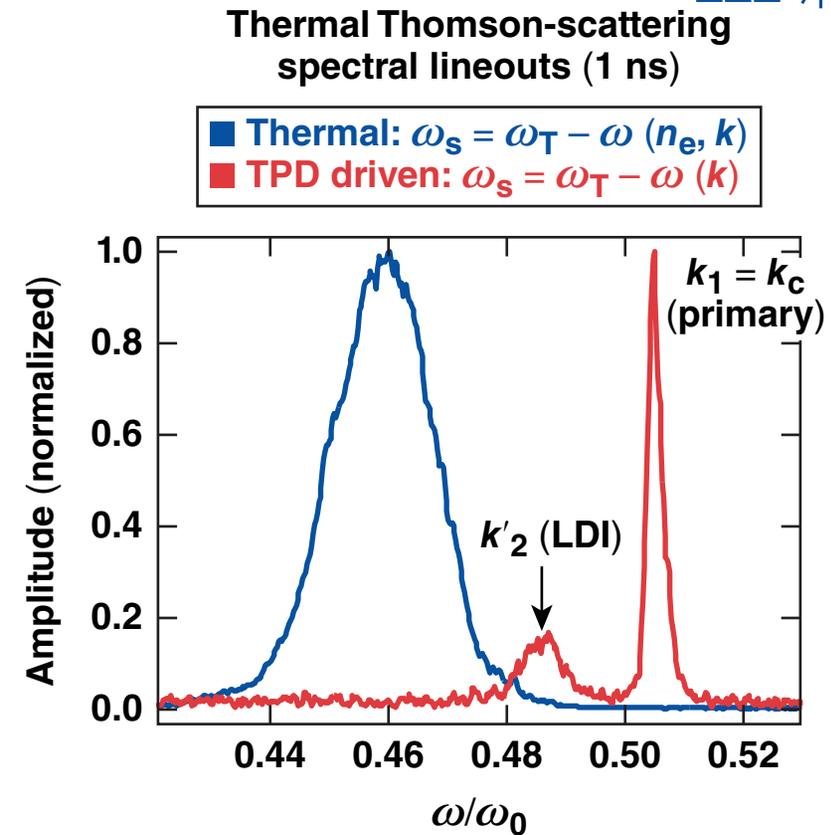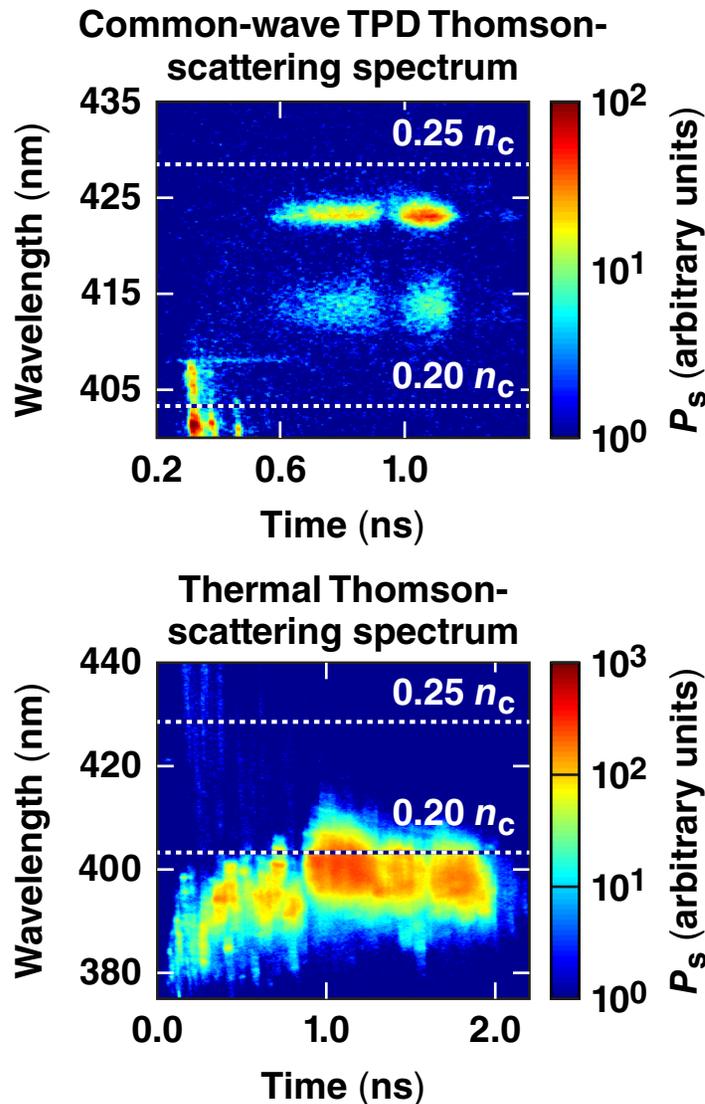
The low-frequency peak is consistent with scattering from backscattered TPD waves, but the TS geometry does not k match.

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Langmuir decay of backscattered TPD EPW's can generate waves that *k* match the Thomson-scattering geometry

Langmuir decay *k* matching

k_y

k_T

$k_{0,i}$

$k_1 = k'_2$

k_s

k_x

k_{IAW}

(k_2, ω_2)

Range of observed densities in Thomson-scattering volume

Primary forward-scattered EPW's (k_1)

Secondary backscattered EPW's (k_2)

n_e/n_c

ω'_2

$n_c/4$

y (μm)

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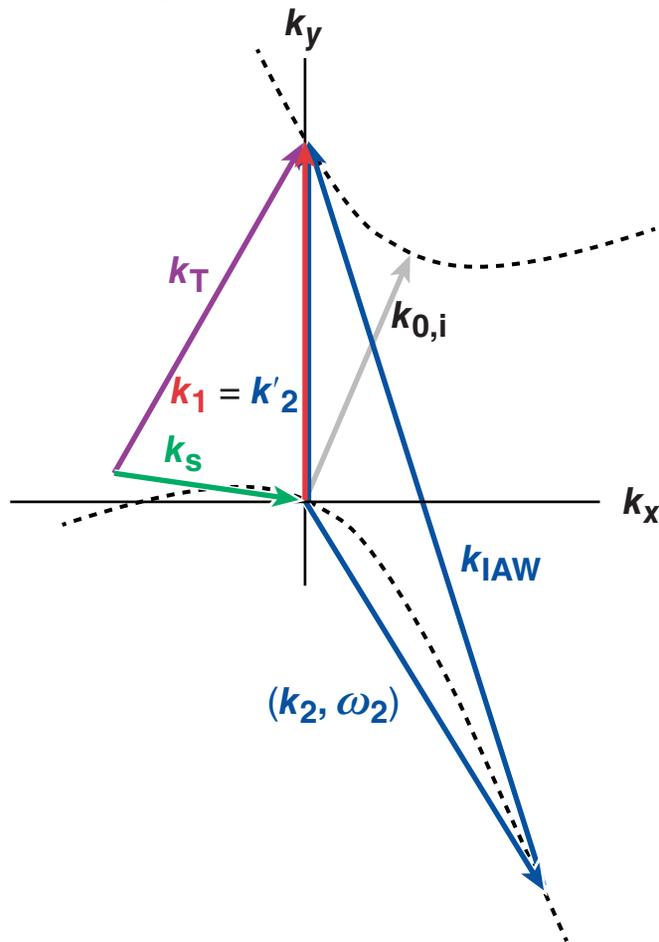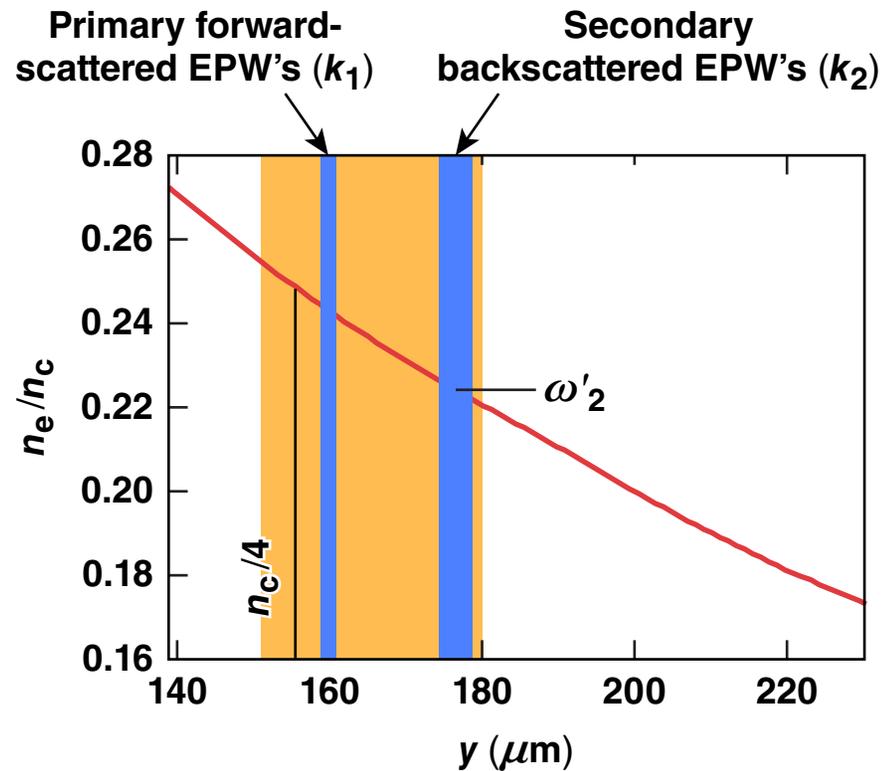
The frequencies of the primary and LDI peaks calculated from the linear dispersion relations and the TPD maximum-growth hyperbola are consistent with the experiment

Thomson-scattering spectral lineout ($t = 1$ ns)

Langmuir decay of
backscattered EPW's

Forward-scattered
common-wave EPW's

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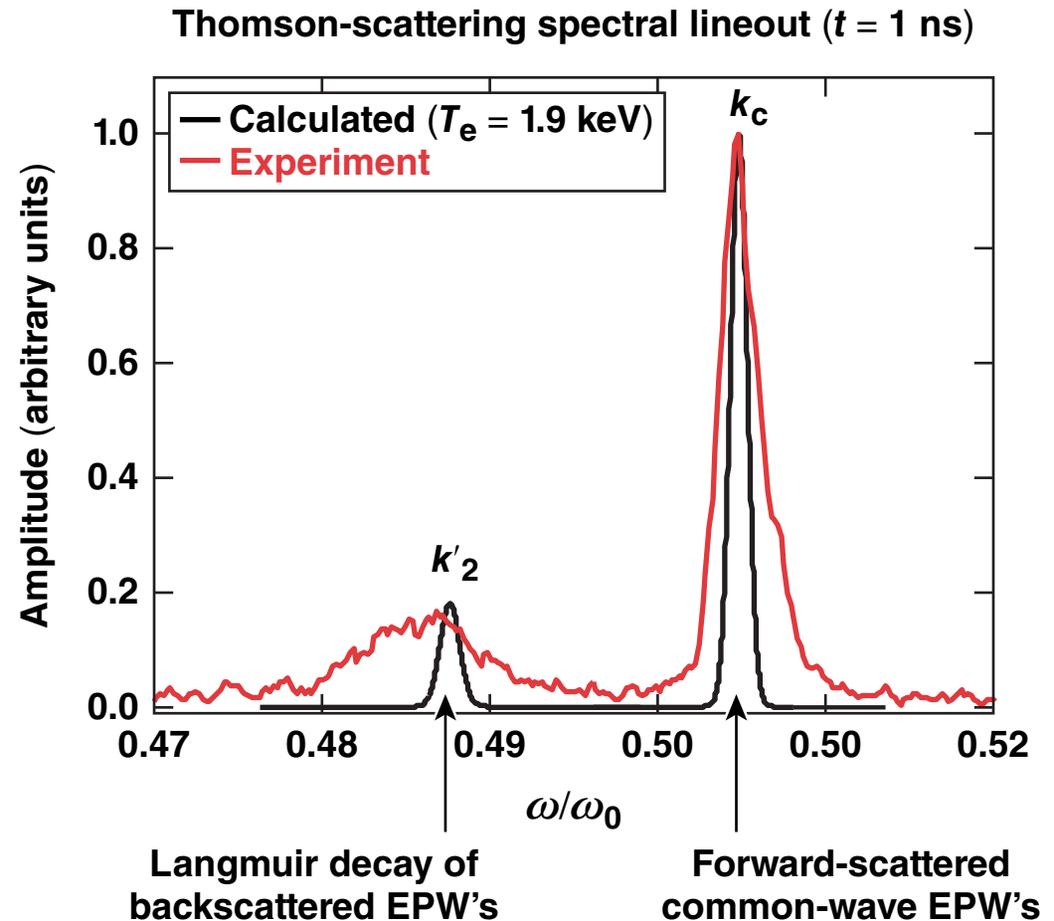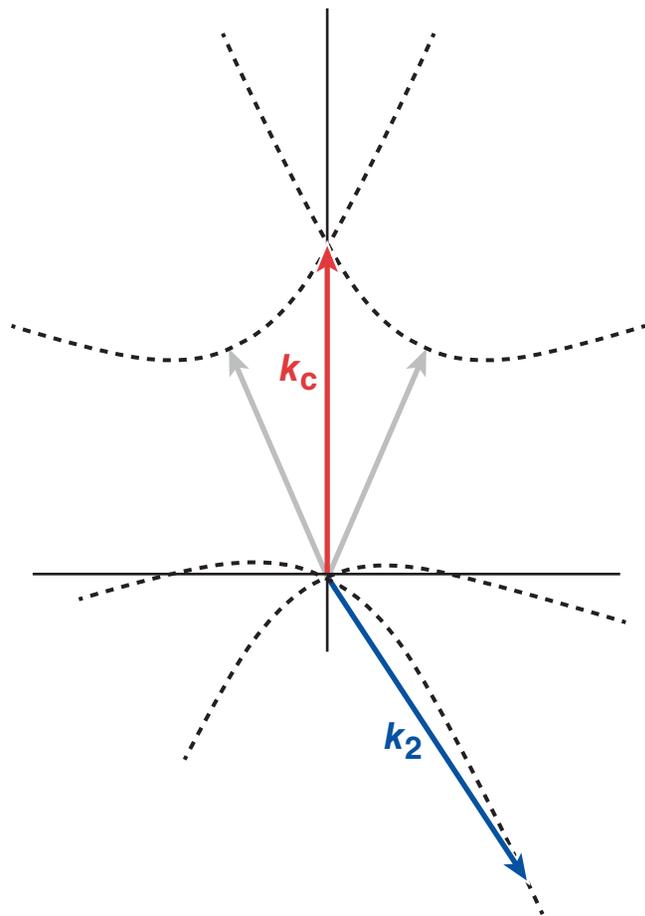
An alternate Thomson-scattering geometry was used to observe a region of *k* space off of the maximum growth hyperbola

Off-hyperbola experimental configuration
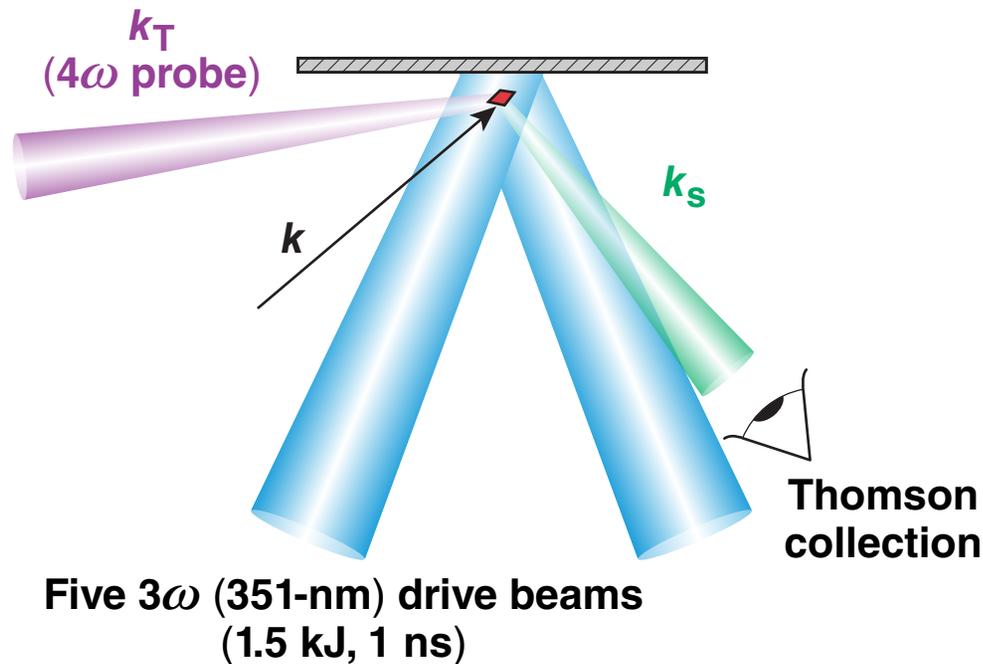
Off-hyperbola *k* matching

k_T
(4ω probe)

k_S

k

Thomson collection

Five 3ω (351-nm) drive beams
(1.5 kJ, 1 ns)

k_T

k_S

k
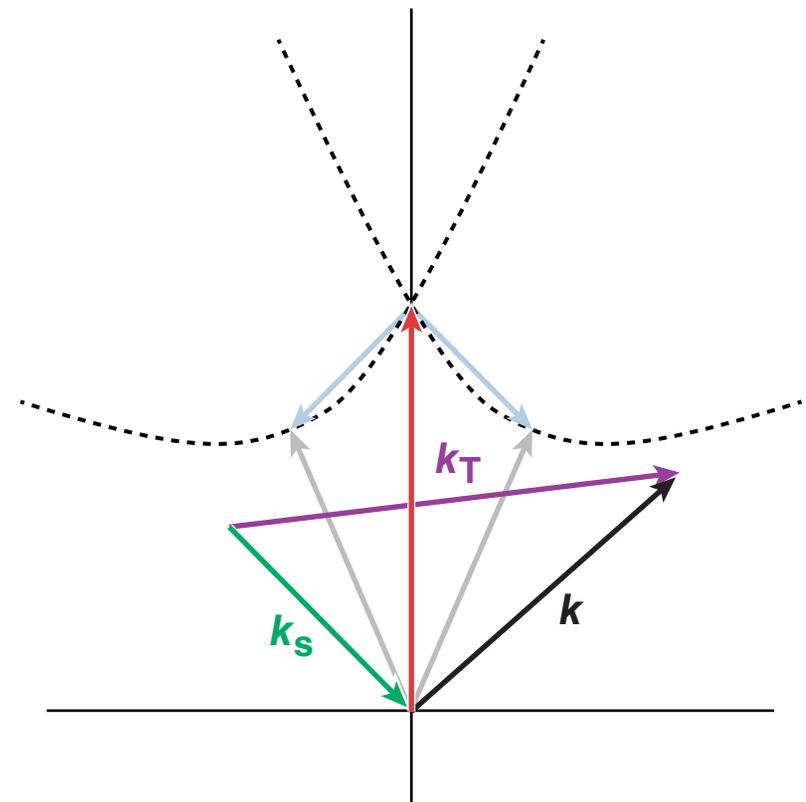
From linear theory, no driven waves are predicted in the off-hyperbola configuration.

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A broad TPD driven spectrum is observed in the off-hyperbola configuration

TS spectrum in off-hyperbola configuration

TS spectral lineouts (1 ns)

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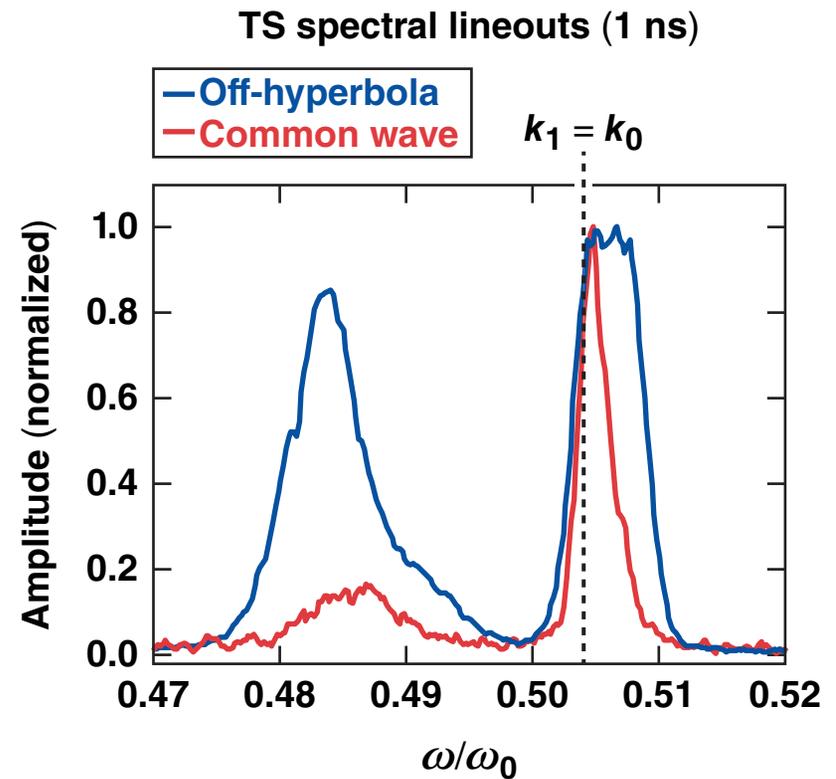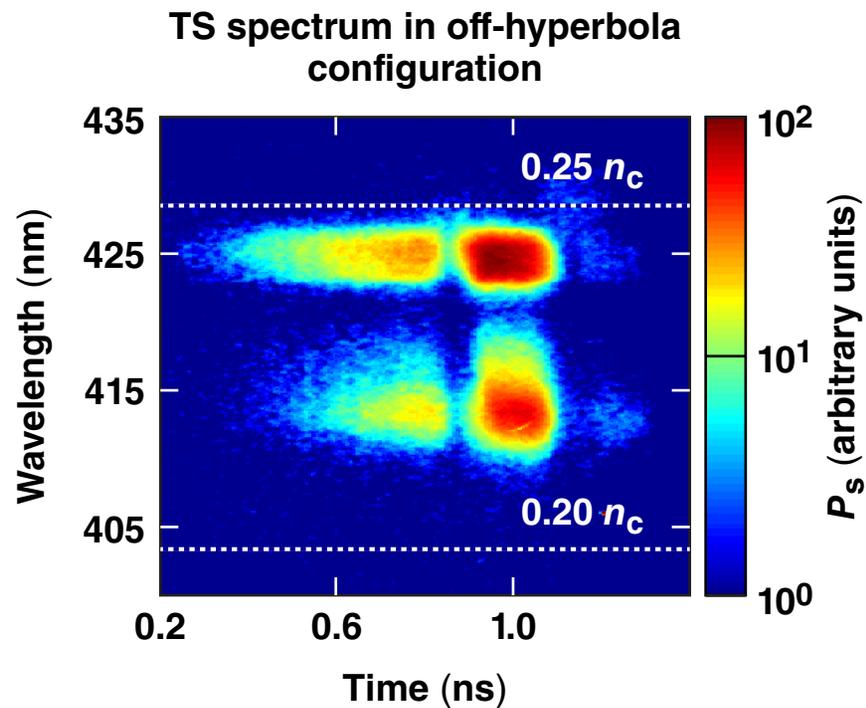
The broad spectrum is consistent with *k* space saturation of TPD driven waves

- The observed frequency range indicates TPD growth from k_0 to $2k_0$
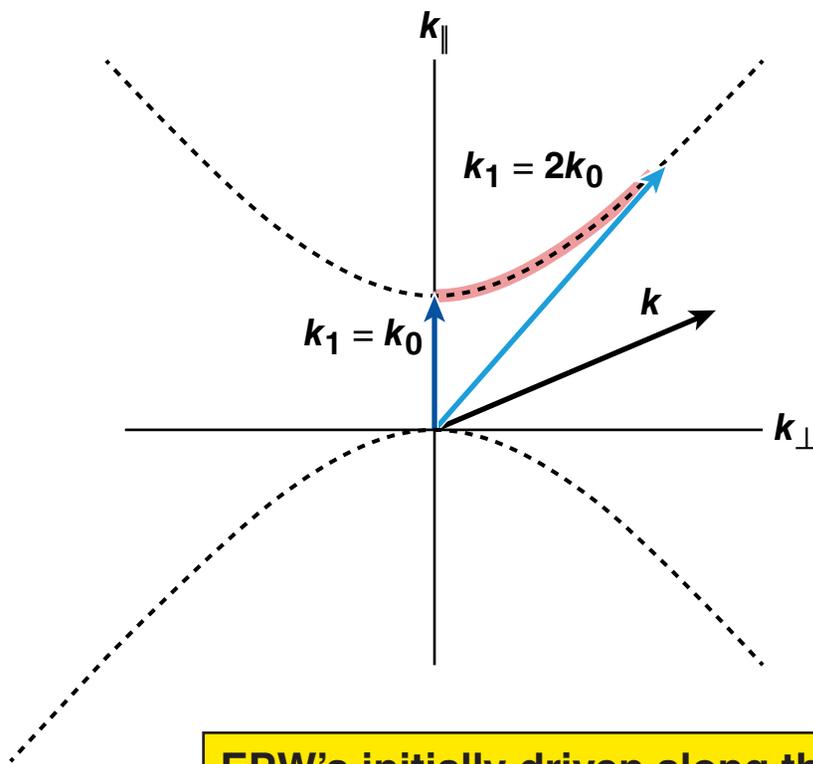
Off-hyperbola spectral lineout
$(t = 1 \text{ ns})$
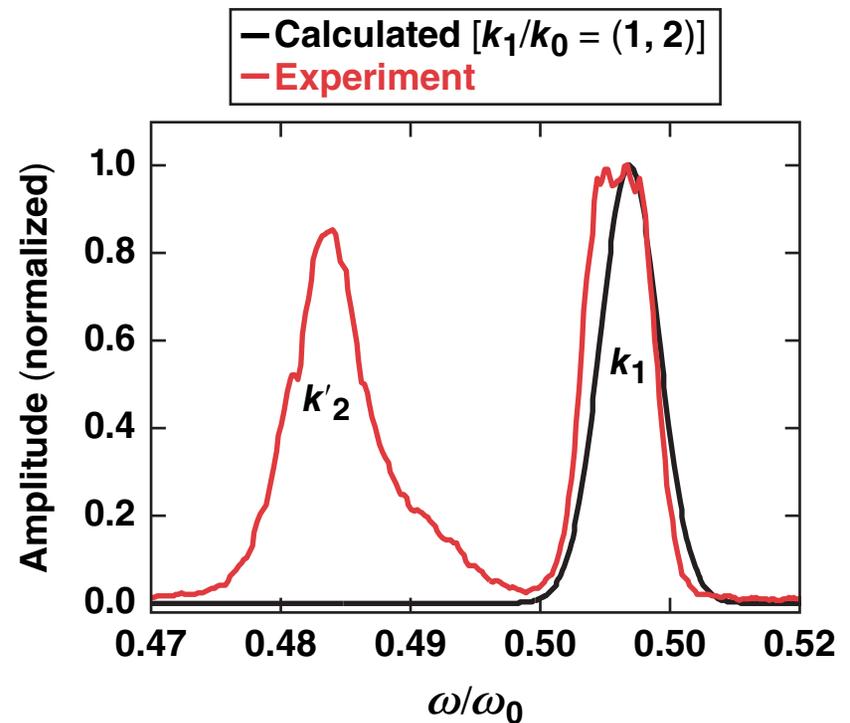
EPW's initially driven along the TPD maximum-growth hyperbola are modified such that they *k* match the Thomson diagnostic (e.g., propagation or scattering).

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The lower-frequency peak is consistent with a calculated spectrum using the *k*-vector range inferred from the forward-scattered peak (k_0 to $2k_0$)

Off-hyperbola spectral lineout
($t = 1$ ns)

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