Self-Consistent Calculation of Half-Harmonic Emission Generated by the Two-Plasmon–Decay Instability

\[ |E_T(\theta, \Delta f)|^2 \]

Emission angle \( \theta \)

- 1°
- 5°
- 8°
- 10°

\( \omega_0/2 \) emission generated by linear mode conversion of two-plasmon–decay plasma waves

Arbitrary units \( (\times 10^{-6}) \)

\( \Delta f \) (THz)

Red → Blue

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Summary

Half-harmonic emission generated by two-plasmon decay (TPD) is calculated with a new code—EMZAK

• Half-harmonic emission is an important experimental observable of TPD*
• Reduced and driven Zakharov equations** are expanded to include transverse fields
• For small scattering angles, linear and nonlinear conversion dominates at the red shift; for large scattering angles, nonlinear conversion and Thomson down-scattering (TDS) dominates at the blue shift

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Collaborators

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EMZAK is used to simulate three competing half-harmonic–generation mechanisms driven by TPD

- Electromagnetic (EM) Zakharov equations† in 2-D
  - here $E = E_L + E_T$ contains both longitudinal and transverse components
    - $\delta N$ static density inhomogeneity
    - $\delta n$ evolving density fluctuation

\[
\begin{align*}
2i\omega p e_0 (D_t + \nu_e) + 3V^2 e_0 (\nabla \cdot \nabla) - c^2 \nabla \times \nabla \times - \frac{4\pi e^2}{m_e} (\delta n + \delta N) \bigg] E &= \\
\frac{e}{4m_e} \left[ \nabla (\bar{E}_0 \cdot \bar{E}^*) - (\nabla \cdot \bar{E}^*) \bar{E}_0 \right] e^{-i\omega t} + S_E
\end{align*}
\]

TPD (longitudinal part), TDS (transverse part)

\[
[D^2_t + 2\nu_i \cdot D_t - c_s^2 \nabla^2] \delta n = \frac{\nabla \cdot |E|^2}{16\pi m_i} + \frac{1}{4} \frac{\nabla \cdot |E_0|^2}{16\pi m_i}
\]

D. A. Russel and D. F. DuBois, Phys. Rev. Lett. 86, 428 (2001);
Linear-mode conversion is the inverse of the more-familiar resonant absorption

- Mode conversion is illustrated from a plane incident Langmuir wave (LW)

\[
\eta = \frac{\left| E_{\text{converted}} \right|^2}{\left| E_{\text{total}} \right|^2}
\]

\[ q = (\omega L/c)^{2/3} \sin^2(\theta_0) \]

When TPD is the source of Langmuir waves, Langmuir-decay instability (LDI) and density-profile modification create more possibilities for half-harmonic emission generation.

Energy spectrum of longitudinal field $|E_L(k_x,k_y)|^2$ averaged over 10 ps

$E_L(x,\omega)$

Expected LW turning point as function of $\Delta\omega$

$\Delta\omega/\omega_0$

$\nabla n_e \rightarrow x (\mu m)$

Quarter-critical density

$n_e/n_c = n_{e0} (1 + x/L)$
Linear-mode conversion has a strong dependence on emission angle

\[ |E_T(x = 26 \mu m, \theta, \Delta f)|^2 \]

- \( |E_T|^2 \) is the square of the absolute value of the scattered EM wave

\[ \Delta f = \Delta \omega / 2\pi \]
\[ \Delta \omega = \omega - \omega_0 / 2\pi \]
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\[ \Delta \omega = \omega - \omega_0 / 2\pi \]

Peak emission occurs at \(\theta \leq 5^\circ\) and is red shifted by \(\sim 10\) THz; there is very little emission for \(\theta \gtrsim 8^\circ\)
The nonlinear conversion happened mainly near the turning point of the Langmuir wave

\[ E_T(x = 26 \, \mu m, \theta, \Delta f)^2 \]

- Similar amplitude to linear-mode conversion
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\[ |E_T(x = 26 \, \mu m, \theta, \Delta f)|^2 \]

- Similar amplitude to linear-mode conversion

Peak emission occurs again for small angle \( \theta \leq 5^\circ \); a significant blue component persists for \( \theta \geq 10^\circ \).

- We speculate that this is associated with the TPD common wave interacting with ion-acoustic wave (IAW) turbulence
Only plasmons with a similar $k$ vector to that of the laser are able to generate half-harmonic emission through Thomson down-scattering.

For $\theta \geq 10^\circ$, all emissions are blue shifted.
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