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Electron Acoustic Waves in Pure Ion Plasmas[1]

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Electron Acoustic Waves (EAWs) are the low frequency branch of electrostatic plasma waves; these waves exist in neutralized plasmas,[3] pure electrons,[4] and pure ion plasmas. The EAWs typically have a phase velocity $V_{\mathrm{phase}}/V_{\mathrm{th}} \sim 1.4$, quite low compared to typical plasma waves. Linear Landau damping would suggest that such slow phase velocity waves are strongly damped; but at finite wave amplitudes, trapping of particles at the phase velocity effectively flattens the distribution function, resulting in a "BGK-like" state with weak damping. Our experiments on standing $m_z = 1$, $m_\theta = 0$ waves show that the small-amplitude dispersion relation for both fast Trivelpiece-Gould (TG) and slow (EAW) plasma modes is in close agreement with the "thumb-shaped" dispersion relation predicted by kinetic theory neglecting damping.[5,6] However, the surprise here is that a moderate amplitude "off-resonant" drive readily modifies the velocity distribution so as to make the plasma mode resonant with the drive frequency. We have observed the plasma adjusting its velocity distribution so as to become resonant with a 100 cycle drive ranging from 10 kHz to 30 kHz. With a chirped frequency drive,[7] the particle velocity distribution suffers extreme distortion, and the resulting plasma wave is almost undamped with $\gamma/\omega \sim 10^{-5}$. Laser-Induced-Fluorescence measurements of the wave-coherent particle distribution $f(\mathrm{v_z},\mathrm{t})$, clearly show particle trapping in the EAW, with trapping widths as expected from theory considering two non-interacting traveling waves forming the standing wave. The coherent $f(\mathrm{v_z},\mathrm{t})$ measurement also shows that particles slower than the wave phase velocity $\mathrm{v_{ph}}$ oscillate in phase with the wave, contrasting with the 180° out-of-phase response of the particles moving faster than $\mathrm{v_{ph}}$. The differing response of the fast and slow particles results in a small net fluid velocity, because the electrostatic restoring force is almost totally balanced by the kinetic pressure, consistent with the low frequency nature of EAW.

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