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Observation of Fluid and Kinetic Nonlinearities for Langmuir Waves Driven by Stimulated Raman Scattering

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Understanding the growth and saturation of laser-driven parametric instabilities such as stimulated Raman scattering (SRS) is important for the success of laser fusion. This instability can occur over a large region of the underdense plasma in targets designed to achieve ignition, such as those for the National Ignition Facility (NIF), and may also constrain experimental designs for other high-energy-density physics experiments planned on NIF. SRS can significantly reduce laser energy absorption, and can preheat the fusion capsule due to fast electrons. Quantitative prediction of the onset and saturation of SRS under given laser and plasma conditions is a goal of research in this field, and will lead ultimately to its control.

SRS is a three-wave process involving the resonant decay of the incident laser wave into a scattered light wave and an electron plasma wave, and must satisfy the frequency and wave-vector matching conditions

$$\begin{aligned} \omega_0 &= \omega_s + \omega_{epw} \\ \vec{k}_0 &= \vec{k}_s + \vec{k}_{epw} \end{aligned} \qquad (1)$$

where ω, $\vec{k}$ are the frequency and the wave-vector of the waves, and the subscripts (0, s, epw) refer to the incident, scattered, and electron plasma wave (EPW). The EPW dispersion is approximated by $\omega_{epw}^2 \approx \omega_p^2\left(1 + 3k_{epw}^2\lambda_D^2\right)$ for small $k_{epw}\lambda_D$, where $\lambda_D = v_e/\omega_p$ is the electron Debye length, $\omega_p = \sqrt{4\pi n_e e^2/m_e}$ is the electron plasma frequency which depends on the electron plasma density n_e, and v_e is the electron thermal speed, $v_e = \sqrt{T_e/m_e}$.

EPW nonlinear mechanisms may saturate the growth of SRS. One mechanism, the Langmuir decay instability (LDI), is where the SRS daughter EPW can resonantly decay into a second, backscattered EPW and an ion acoustic wave[1]. If this process is driven strongly, a cascade of multiple LDI steps is possible. LDI can saturate the growth of SRS since the LDI EPWs are non-resonant with SRS, and energy is dissipated from the SRS daughter EPW.

LDI is a fluid-like nonlinearity, involving wave-wave coupling, and occurs predominantly when Landau damping is weak, i.e. $k_{epw}\lambda_D < 0.2 - 0.3$.

Electron trapping, a kinetic nonlinear effect (wave-particle coupling), can occur for large amplitude EPW when electrons are trapped in the potential troughs of the wave. In addition to experiencing a reduction in the linear Landau damping rate, the EPW frequency decreases in proportion to the wave amplitude, thus making the EPW non-resonant with SRS and saturating its growth[2]. Electron trapping can occur to some extent at all $k\lambda_D$, but its effect is stronger at higher $k\lambda_D$ where the nonlinear frequency shift is large[2].

Experimental observation of these effects is often masked by plasma inhomogeneity since the frequency shifts associated with LDI or trapping are quite small, $\delta\omega/\omega_p \sim 0.01$, and requires extremely homogeneous plasma conditions to discern these phenomena. We have developed an experimental platform, namely single hot spot interaction experiments, where a nearly diffraction-limited laser interacts with a preformed plasma. The laser focal spot size, ~ 2 μm, is much smaller than the density gradient scale lengths, and the interaction occurs in extremely uniform conditions, allowing the detection of the subtle signatures of LDI and trapping[3].

The experiments are performed at the Los Alamos Trident laser facility, and use ~400 J of 527-nm laser light to irradiate a CH target in a 1-ns pulse, forming a 1-mm scale plasma with T_e decreasing from 700 to 500 eV after the heater beams have turned off. Electron densities in the range of $n_e = 1 - 3 \times 10^{20}$ cm^{-3} are accessed 600 – 800 μm in front of the target. After the heater beams are off, a 527-nm nearly diffraction-limited laser (single hot spot) interacts with the plasma to drive SRS with laser intensity $10^{15} - 10^{16}$ W/cm^2. In addition to measuring the SRS backscattered light and spectrum, Thomson scattering from a 351-nm laser is employed to detect the time-resolved spectrum of driven EPWs and to diagnose the background plasma temperature and density. The experimental layout is shown in Fig. 1.

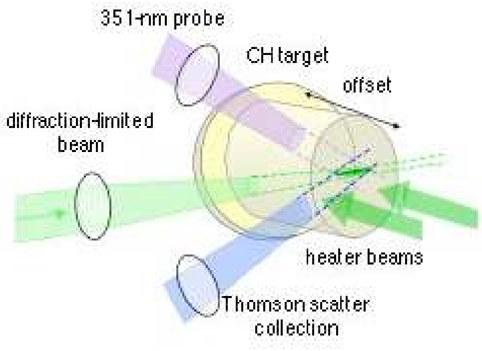

Figure 1

Fig. 2a – 2c shows the time-resolved Thomson scattered spectra from experiments where the electron density was varied between (a) n_e/n_{cr} = 0.049, (b) n_e/n_{cr} = 0.044, and (c) n_e/n_{cr} = 0.034, where n_{cr} is the critical density for 527-nm light ($n_{cr} \approx 4 \times 10^{21}$ cm^{-3}). Since T_e is cooling from 700 – 500 eV during the time of the 200 psec interaction pulse, $k\lambda_D$ is slightly decreasing during each experiment, with $k\lambda_D$ at mid-time of 0.27, 0,29, and 0.34 respectively. LDI is only observed to occur when $k\lambda_D \leq 0.3$ in these experiments. For $k\lambda_D >$ 0.3, the spectrum is significantly broadened due to electron trapping.

The angle-resolved Thomson scatter spectrum can be directly related to (ω, k) to obtain a dispersion diagram of the driven waves[3]. Fig. 3a – 3b shows gated Thomson (ω, k) spectra for experiments where (a) $k\lambda_D \approx 0.30$ and (b) $k\lambda_D \approx 0.36$. In Fig. 3a, discrete (ω, k) steps are observed, and are consistent with up to 4 steps of LDI cascade. In Fig. 3b, a frequency-broadened spectrum is observed, within a relatively narrow range of wave-numbers compared to that of LDI cascade. This spectrum is qualitatively consistent with electron trapping, where the broadening is due to the trapping-induced nonlinear frequency shift.

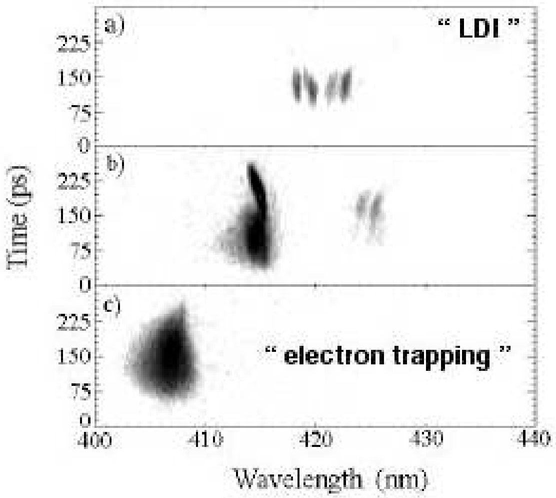

Figure 2a – 2c

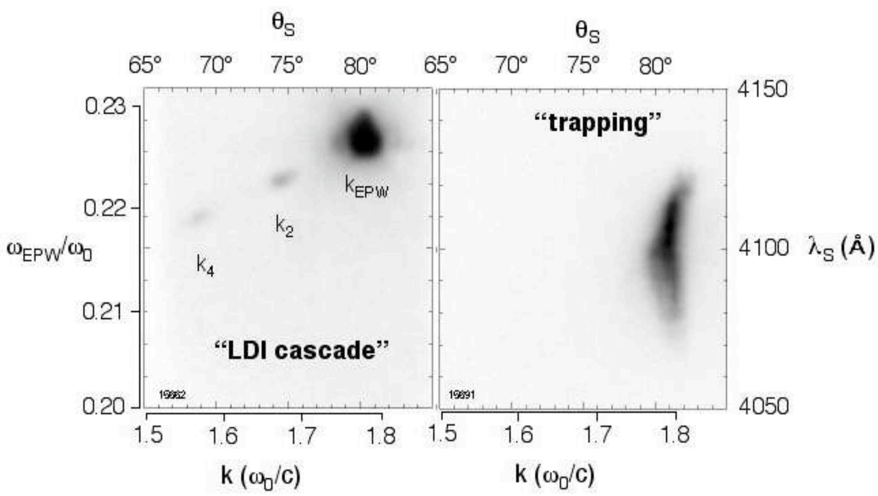

Figure 3a – 3b

In summary, these experiments allow the observation of the subtle signatures associated with LDI and trapping, and are guiding the development of quantitative predictive theoretical models for the growth and saturation of SRS. This research was performed under the auspices of the DOE/NNSA by LANL under contract W-7405-ENG-36.

1. D.A. Russell, D.F. Dubois, H.A. Rose, *Phys. Plasmas* **6**, 1294 (1999).
2. H.X. Vu, D.F. DuBois, B. Bezzerides, *Phys. Plasmas* **9**, 1745 (2002); H.A. Rose, D.A. Russell, *Phys. Plasmas* **8**, 4784 (2001).
3. D.S. Montgomery *et al., Phys. Plasmas* **9**, 2311 (2002); J.L. Kline *et al.,* submitted to Phys. Rev. Lett. (2004).