2.B Stimulated Backscatter Measurements in the Laser Matter Interaction Experiments

Stimulated scattering processes of the incident laser light in the underdense plasma are potentially important in laser fusion. We have made observations of spectrally resolved backscatter light from simple planar targets illuminated with the 0.35 μm beam of the GDL laser (< 50 J at 400 psec). The measurements have included time and spectrally resolved measurements close to the incident wavelength to look for evidence of Brillouin scattering. Time integrated measurements in the spectral region between 0.40 and 0.70 μm were made to investigate Raman and two plasmon decay processes.

Under the condition of these experiments (3×10^{13} to 3×10^{15} W/cm^2 at 400 psec, and CH, Ni, or Au targets) we observe both Brillouin and Raman backscatter; the level of backscatter, however, is low ($< 10^{-2}$ for SBS, $< 10^{-6}$ for SRS).

The impact of these effects on future laser fusion experiments are quite different. Brillouin scattering is a process in which the incident electromagnetic (EM) wave is converted to an ion acoustic plasma wave and a scattered EM wave. Since the frequency of the ion acoustic wave is small compared to the EM wave, very little energy is delivered to the plasma by this process. This scattering mechanism is significant principally as an energy loss mechanism which might limit the coupling efficiency of the light to the plasma. In Fig. 14 we show the fraction of the energy

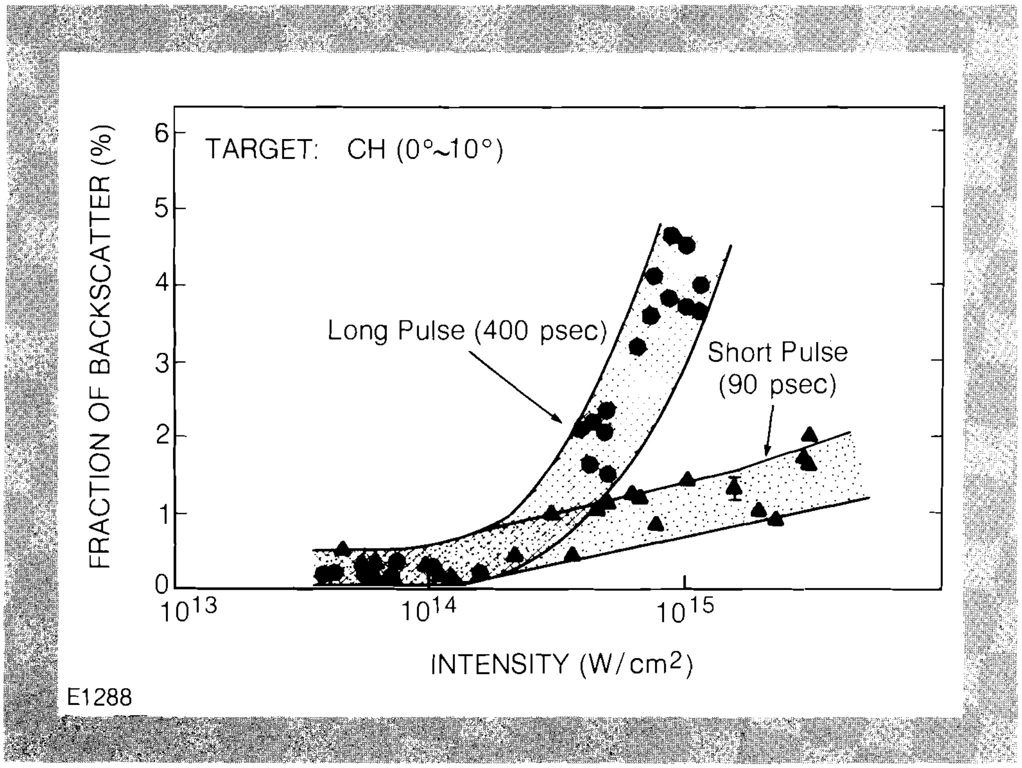


Fig. 14
Percent backreflection versus laser intensity.

that was backscattered through the focusing lens (f/12) by Brillouin-type processes in these experiments. Even at the highest intensities these processes only led to a backscatter fraction of less than 5% of the incident light. However, due to our particular experimental set-up (f/12 focusing lens) we estimate that the real backscatter fraction may be up to twice the measured fraction.

A typical set of time-resolved observations is shown in Fig. 15. This figure shows iso-intensity contours of the backscattered light. In this figure, wavelength dispersion is shown in the vertical direction and time dispersion in the horizontal direction. The three cases are chosen to illustrate the qualitative change in the spectra observed for targets oriented at various angles with respect to the incident beam. The mean value of the spectral shift for the 22° targets is a 1 to 2 Å red shift. This red shift increases slightly as the target angle is increased to 45°. This behavior is interpreted as Brillouin scattering from a flowing plasma with a flow velocity of approximately Mach 1. The 0° – 10° cases show a much broader spectrum with the mean shifted to shorter wavelengths. We tentatively interpret these spectra as being due to scattering from a standing density wave in the plasma. The standing wave arises from four traveling waves, the incident and reflected EM waves plus two ion waves traveling up and down the density gradient of the plasma. This type of interaction is called *modulational instability*[1] scattering.

In Brillouin-like scattering, it is the magnitude of the backscatter fraction which is most important. Figure 14 shows the fraction of

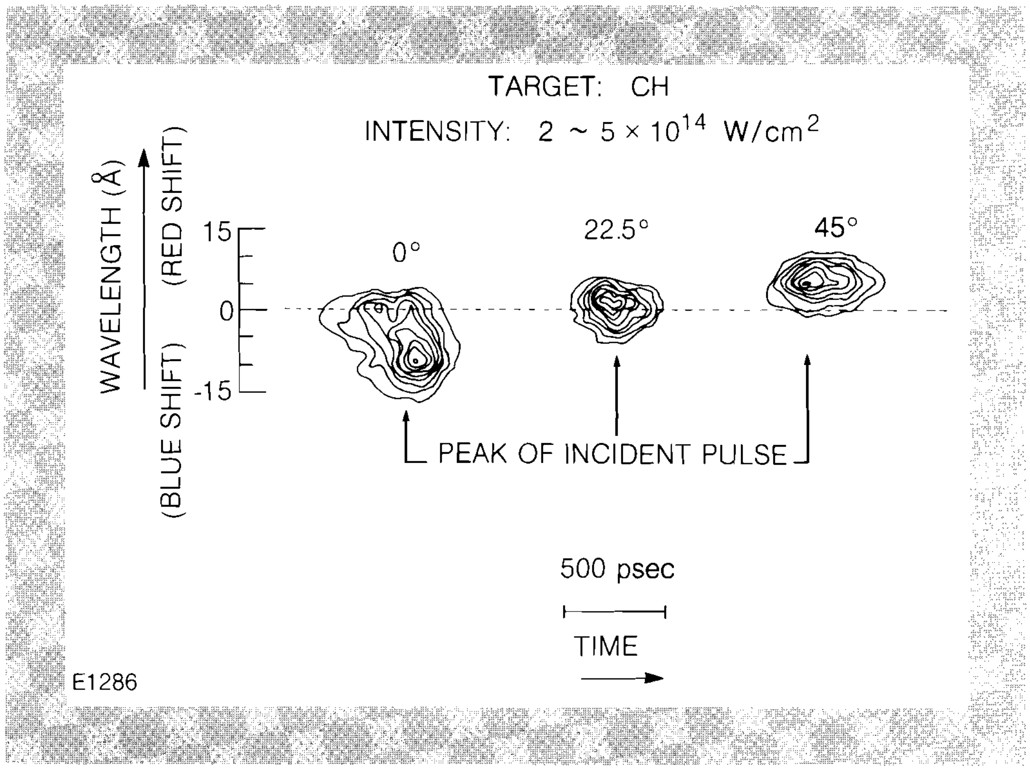


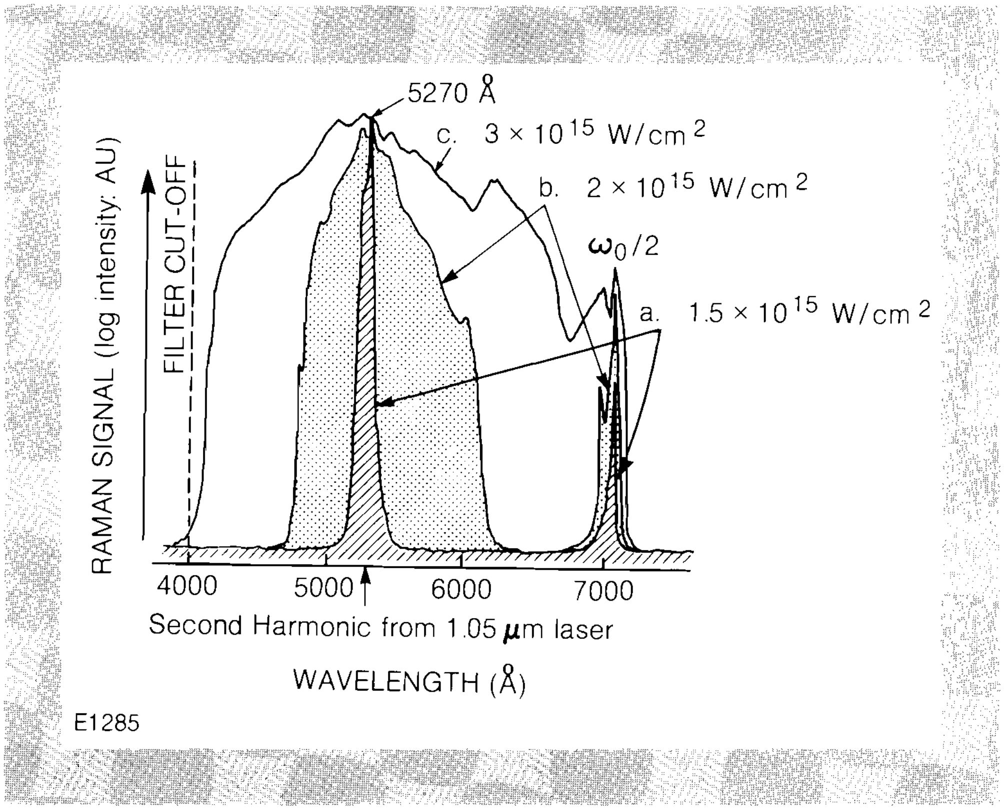
Fig. 15
Time-resolved backscattered spectra from UV laser-produced plasma.

the incident laser energy backscattered by CH targets for 90 and 400 psec pulses. For the 90 psec pulses the backscattering was always less than 2%, suggesting that in these experiments the scale lengths were short enough that the threshold for stimulated scattering was never exceeded. For the 400 psec experiments one notes an increase in backscatter when the average intensity exceeds ~ 10^{14} W/cm². Up to intensities of 10^{15} W/cm the backscatter increases to 5% with no evidence of saturation. It should be noted, however, that the increase is approximately linear with intensity and not exponential.

The Raman and the two plasmon decay processes involve the conversion of the incident EM wave into either one plasma wave and one EM wave (Raman) or two plasma waves ($2\omega_p$ decay). Due to the matching conditions, these processes can only occur at densities less than or equal to quarter critical ($n_c/4$). Both the two plasmon decay and the absolute Raman instabilities can only occur very close to the quarter critical density. (An absolute instability is one which is stationary in space and growing in time.) Another type of Raman instability, the convective Raman instability, occurs at densities below $n_c/4$. This instability involves growing electrostatic plasma waves which move through the plasma.

To observe these effects we have made time integrated, spectrally resolved measurements in the region between 4000 and 7500 Å. Observations were made of light backscattered through the illuminating f/12 lens and at 45° to the incident beam

Fig. 16
Stimulated Raman Backscatter from CH targets for different laser intensities.



with an f/3 collecting lens. A typical series of backscatter spectra is shown in Fig. 16. The spectrum shown in curve (a) was taken very close to threshold and shows signals at 7000 Å attributed to the absolute Raman instability and at 5270 Å. The latter arises from convective Raman backscatter driven by a residual green (5270 Å) component present in the incident beam and due to incomplete suppression of the lower harmonics in our UV irradiation facility. Curve (b) was taken at twice the threshold intensity. It shows significant scattering from 4000 to 7000 Å. The two peaks near 7000 Å are again assigned to the absolute Raman instability. The shorter wavelength scattering is attributed to the convective Raman instability. A plot of the Raman intensity versus incident laser intensity is shown in Fig. 17. These curves show very clear threshold behavior for both the absolute instability

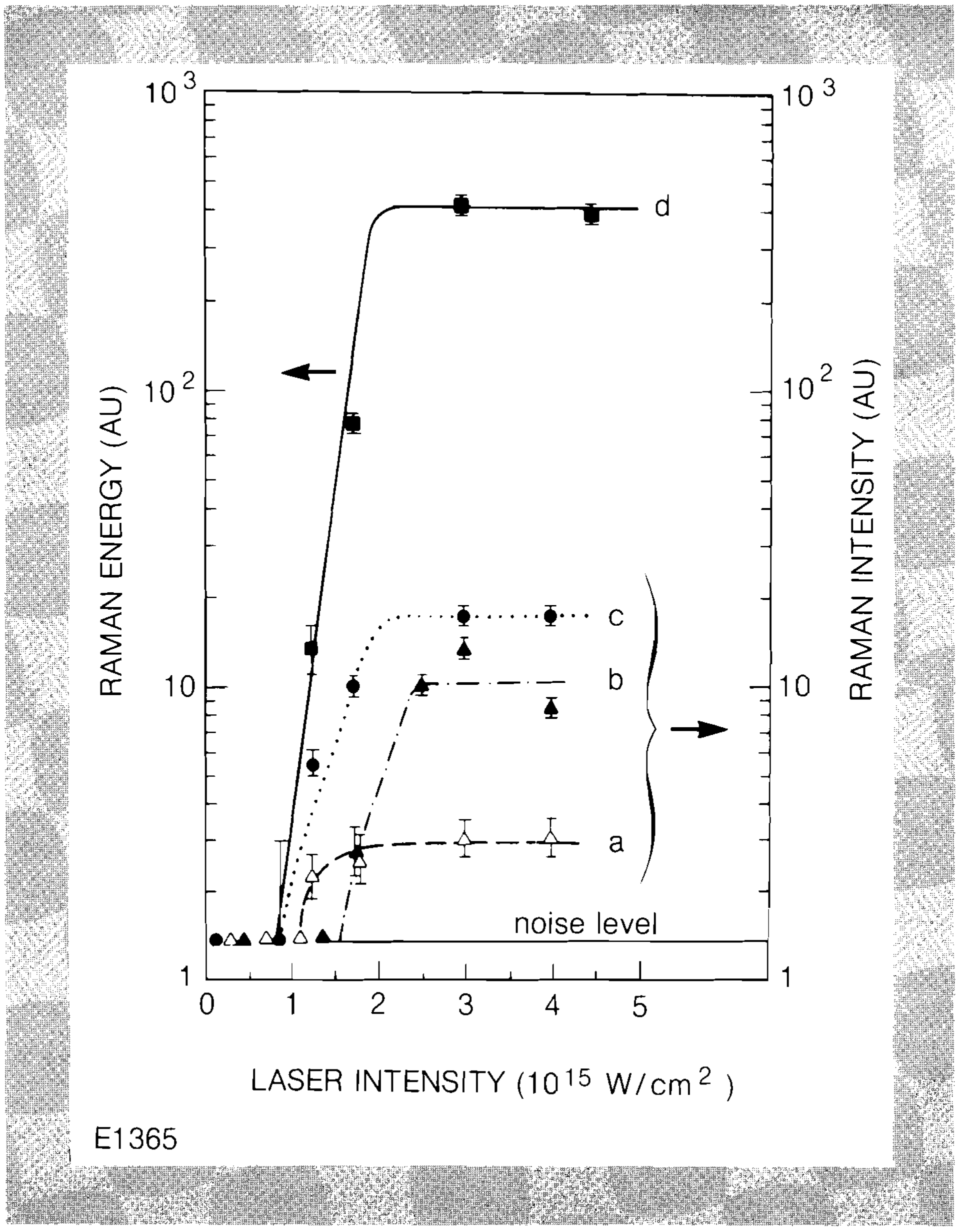


Fig. 17
Dependence of Raman instability on incident laser intensity. (a) absolute instability at 7000 Å, (b) convective instability at 6000 Å, (c) convective instability at 5270 Å, (d) energy of Raman scattered light.

[curve (a)] and the convective instability [curve (b)]. Curve (d) shows the total energy in backscatter in the Raman spectral region and shows an exponential growth followed by a clear saturation. This saturation at very low levels ($\sim 10^{-6}$ of the incident laser energy) is a very encouraging result.

The thresholds for the convective and absolute instabilities are observed to be almost equal. If the effective density scale lengths were the same for both processes the theoretical calculations[2] would predict thresholds which would differ by almost an order of magnitude. From the threshold evidence (Fig. 17), as well as the minimum in the backscattered spectrum at 6600 Å [Fig. 16, curve (b)], we conclude that there must be a steepening of the density profile at quarter critical. This has been predicted in simulations[3] where the steepening was shown to be caused by the two plasmon decay instability.

We do not believe the direct backscatter light at 7000 Å to be due to reconversion of plasma waves back into EM waves because the scattering was found to be highly polarized and we sampled the backscattering only over a very small angle (f/12 cone). In contrast, measurements made at 45° on targets oriented at 45° with respect to the laser beam showed a much lower degree of polarization for the 7000 Å light. However, the same high degree of polarization was found for the shorter wavelength scattering. The difference is attributed to the use of a larger aperture lens (f/3) at 45° compared to the f/12 for direct backscattering. Since reconversion of the plasmons into EM waves is the inverse of resonance absorption, one expects a minimum in reconversion normal to the target. Experiments to elucidate the difference between absolute Raman and two plasmon decay instabilities are continuing.

These experiments clearly show that both absolute and convective Raman scattering occur for plasmas produced by 400 psec, 0.35 μm light interactions. Fortunately for laser fusion, these instabilities appear to be saturated at rather low levels. The saturation mechanisms are still not well understood.

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