Clayton et al. Respond

C.E. Clayton*       C. Joshi†
C. Darrow‡         Donald P. Umstadter**

*University of California, Los Angeles
†University of California, Los Angeles
‡University of California, Los Angeles
**University of Nebraska-Lincoln, dpu@unlserve.unl.edu

This paper is posted at DigitalCommons@University of Nebraska - Lincoln.
http://digitalcommons.unl.edu/physicsumstadter/37
Clayton et al. Respond: The authors of the Comment\footnote{F. Martin et al., preceding Comment [Phys. Rev. Lett. 55, 1651 (1985)].} are quite correct when they point out that the ruby-laser scattering system used in our study\footnote{C. E. Clayton et al., Phys. Rev. Lett. 54, 2343 (1985).} can only respond to beat-excited density fluctuations with $k_y = k_z$, where the CO$_2$ (ruby) beam propagates in the $z$ ($y$) direction. Thus the data in Fig. 2(a) of the Letter\footnote{P. Lavigne et al., Phys. Fluids 28, 409 (1985).} do not represent the $k_z$ spectrum with $k_y = 0$ as supposed, but rather the $k_y$ spectrum at $k_y = \omega_p/c$, where $\omega_p$ is the plasma frequency.

Before revising the conclusions of Ref. 2, we would like to clarify a few points. In the Comment the authors conclude that “plasmons . . . near $c$ await measurement and confirmation still.” According to their Eq. (3) these plasmons can only be seen when the scattering angle $\theta_s$ is near zero, which requires that the probe beam be coaxial with the CO$_2$ beam. But this was precisely the case for the forward-Thomson-scattered CO$_2$-light measurements. The forward-scattered CO$_2$ signals (Stokes and anti-Stokes lines) were found with the following properties: (1) were observed only under the two-frequency illumination; (2) had a density (pressure) resonance; (3) had a growth time of approximately 400–500 psec, consistent with the time to saturation predicted by fluid theory; and (4) were correlated with an (independent) ruby Thomson-scattered signal. These are properties that one expects of light scattered from a collinear beat-excited plasma wave. [The sideband observations of Lavigne et al.\footnote{P. Lavigne et al., Phys. Fluids 28, 409 (1985).} mentioned in the Comment do not include items (2)–(4) listed above, nor were those measurements made in the forward direction with an underdense plasma, and so we do not find those observations relevant to this discussion.] The scattered CO$_2$ light was collected in an approximately $f/15$ cone, with use of Eq. (3) of the Comment, implies contributions to the scattered light from plasmons with phase velocity $v_p$ in the range $c \gg v_p \gtrsim 0.85c$. Thus we feel that high-phase-velocity plasma waves have indeed been detected in this experiment, as concluded in the original Letter.

In regard to the interpretation of Fig. 2(a) from the Letter, we note that in the real, three-dimensional world, the two-frequency CO$_2$ pump can excite plasmons over a broad region in $k$ space, as shown in Fig. 1. The shape and extent of the $k_y$ spectrum $S(k_x, k_z = k_y)$, where $k_y = \omega_p/c$, depends on the profile of the input CO$_2$ beam and the focusing $f$ number, respectively. Our $f/7.5$ focusing implies that plane-wave components of the pump beams can mix at angles up to $7.6^\circ$, which gives a cutoff of the $k_y$ spectrum at $k_y = 1.23k_p$. Note that a symmetric $k_y$ spectrum such as shown in Fig. 1 implies that the plasma wave has not a periodicity in the $y$ direction but rather a finite radial extent. Note also that the velocity of phase fronts due to the interference of plasmons with $k_y \hat{z} \pm k_p \hat{y}$ is approximately $c$, so that these $k$ components are indeed associated with the high-phase-velocity electron plasma wave. If the pumps were plane waves, the plasma-wave amplitude would be proportional to the product $E_0(k_0)E_1(k_y)$. If, however, the pumps are focused beams with plane-wave spectra\footnote{J. W. Goodman, Introduction to Fourier Optics (McGraw-Hill, New York, 1968).} $F_0(k_0)$ and $F_1(k_1)$, where $k_p = k_1 \cdot \hat{y}$, the plasma-wave amplitude at a certain $k_y$ [i.e., $S(k_x, k_z = k_y)$] is proportional to the convolution of $F_0(k_y)$ with $F_1(k_y)$ up to relativistic saturation. From Fourier optics calculations, we can estimate the $F_1(k_p)$ from our radial pump-intensity profiles at the CO$_2$ input lens. By performing the convolution, we get an estimate for $S(k_x, k_z = k_y)$ which is down a factor of 3–5 for $k_y = k_p$ compared to $k_y = 0$. Collective Thomson scattering probes this $k$-space representation of the plasma-wave density fluctuations, giving a scattered field proportional to $S(\Delta k)$. Here, $\Delta k$ is the wave vector to which the scattering geometry is matched, which, for our case, was $\Delta k = k_p \hat{y} + k_2 \hat{\bar{z}}$. Thus the value of the plasma-wave amplitude $\tilde{n}/n_0$ given in the Letter as 1%–3% should probably be revised upward to something like 9% ± 6%, a range more consistent with the fluid theory.

C. E. Clayton
C. Joshi
C. Darrow
D. Umstadter

Electrical Engineering Department
University of California
Los Angeles, California 90024

Received 25 July 1985
PACS numbers: 52.35.Fp, 52.35.Mw, 52.40.Nk

FIG. 1. Representative contour plot of a beat-excited plasma-wave $k$ spectrum $S(k_x, k_z)$ where the pump beams propagate in the $z$ direction.