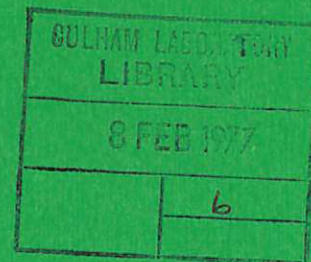


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T P DONALDSON M HUBBARD I J SPALDING

CULHAM LABORATORY
Abingdon Oxfordshire

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REFLECTION AND SCATTERING FROM CO₂ LASER GENERATED PLASMAS

T. P. Donaldson*, M. Hubbard⁺, and I. J. Spalding
Culham Laboratory, Abingdon, Oxon OX14 3DB, England
(Euratom/UKAEA Fusion Association)

The intensity of 10.6 μm radiation scattered from carbon plasmas has been measured as a function of incidence and collection angles (with angular resolution $\leq 1.3^\circ$), and of laser mode structure. Over an incident intensity range of $10^{11} - 10^{13}$ watts cm^{-2} , total reflectivity was typically $\leq 8\%$. At certain angles reflectivity often showed 100% temporal modulation. The relevance of these results to critical-surface and stimulated-scatter phenomena is discussed.

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* Present address Institut für Angewandte Physik, Universität Bern, Switzerland.

⁺ Attached from University of Oxford, and acknowledging an SRC studentship.

The reflection and scattering of radiation from laser-produced plasmas is a topic of active experimental and theoretical interest. Extensive measurements on a wide variety of targets have been reported, for example, at wavelengths of $\lambda = 0.694^{(1)}$, $1.06^{(2-7)}$, and $10.6 \mu\text{m}^{(8-15)}$. In most of these experiments the focusing arrangements were such that the target simultaneously encountered a wide range of angles of incidence (θ). This paper describes measurements made with higher angular resolution than heretofore^(5,12), and discusses the exceptionally strong time-variation of reflectivity which has been observed using multi-mode lasers and the absence of detectable modulation when a laser is operated on a single transverse axial mode.

As shown in Fig. 1, a 75 J, 50 ns pulse from a plane-polarized multimode CO_2 laser of cross-section 5×10 cm was focused by a 7.8 cm dia. 22 cm focal length KCl lens onto a solid graphite target. Radiation back-scattered into the focusing lens, and the incident radiation, were sampled by a 16% NaCl beam-splitter and imaged onto photon-drag detectors PD2 and PD1. Radiation side-scattered into the remaining $\sim 2.0\pi$ steradians was collected by a spherical copper mirror and focused into a photon-drag detector PD3 located behind the target. Variations of absorption with θ were investigated by placing annular apertures at the laser output window (thus restricting the uncertainty in $|\theta|$ to $0.65 - 1.3^\circ$) whilst the back and side-scattered signals were measured into the collection angles of the lens and mirror respectively. Similarly, the distribution of radiation scattered into angles $\varphi \pm \Delta\varphi$ was measured (with the full $f/4.4$ cone of radiation incident) by placing a series of annular apertures before the PD2 imaging lens, giving a resolution $\Delta\varphi = 0.4 - 0.8^\circ$.

Fig. 2 shows the variation with θ of the total back and total side scattered radiation, when the target surface is in the focal plane. Similar results are obtained with the target displaced 1 mm from this plane (diffraction effects are then less important and θ is more meaningfully defined). It is noted that here the mean focal intensity increases with θ ($3.3 \times 10^{11} - 3.6 \times 10^{12} \text{ W cm}^{-2}$) so that the plasma has properties intermediate to those characterized in previous

work^(16,17) ($60 \text{ eV} < kT_e < 1.3 \text{ keV}$). The reflectivity is qualitatively compatible with numerical predictions of strong optical resonance absorption plus inverse bremsstrahlung in inhomogeneous plasmas⁽¹⁸⁾. In common with other experiments using gain-switched TEA lasers⁽¹⁵⁾, the absolute reflectivity was found to be insensitive to target material and incident radiation intensity (within the range $3 \times 10^{11} - 10^{13} \text{ W cm}^{-2}$).

Two features of the subsequent observations are noteworthy: (i) radiation is scattered into preferred angles (Fig.3); (ii) its intensity is strongly modulated^(2,6) (Fig.4(a)). Fig.3(a) shows the preferred scatter angles observed at $10^{13} \text{ W cm}^{-2}$ incident intensity (with no aperture placed before the f/4.4 target lens, so that radiation is incident at a range of angles within the cone defined by the lens aperture shown on the polar diagram). These measurements are insensitive to target position, cf. results discussed for Fig.2. The $0.4^\circ - 0.8^\circ$ resolution of the back-scatter data is indicated by the error bars in Fig. 3(b), which also show the shot-to-shot variation in the signal envelope (evaluated as a mean of 5 - 10 observations made under identical conditions). Angular discrimination for side-scattered radiation was obtained by placing apertures of various diameters in front of PD3, giving a resolution of $\pm 5^\circ$.

A test was made to distinguish back-scattering ($\phi = \pi$) and specular reflection ($\phi = \pi - 2\theta$) by stopping the same half of the incident and back-scattered laser beams with two D shaped masks, so that specular reflection was not detected. The addition of the stop did not reduce the percentage reflectivity, proving that radiation detected by PD2 was predominantly backscattered through π . (In a similar test, using rectangular masks to detect azimuthal asymmetry relative to the incident polarisation plane, the backscattered radiation exhibited only a weak asymmetry). At incident intensities of $10^{11} - 10^{13} \text{ W cm}^{-2}$ the amplitude of the time-resolved back-scattered signal is modulated by 30 - 100%. Fig.4(a) illustrates the particularly strong modulation which occurs at $\theta = 4.5^\circ$, and at wide back-scatter angles. The influence of laser

axial and transverse mode structure on these measurements was investigated by replacing the multimode laser (A) with a single-transverse mode 20 MW CO₂ laser (B) which had a similar risetime (50 ns FWHM) and lased on a single axial mode⁽¹⁹⁾. Spherical aberration in the focusing lens limited the incident intensity to $\sim 5 \times 10^{11} \text{ W cm}^{-2}$. Two important differences were noted: (i) no modulation of the backscattered intensity was observed (cf. Fig. 4(b)); (ii) the backscattered reflectivity increased to $30 \pm 3\%$. When the unstable optical cavities on laser B were readjusted to permit operation on ~ 4 axial modes (within a single transverse mode), strong modulation of the back-scattered signal was observed at a peak intensity of $1.5 \times 10^{12} \text{ W cm}^{-2}$ (Fig. 4(c)), and the reflectivity was $\sim 22\%$. A strong correlation was noted between the periodicity of the observed modulation (using either multi-mode laser) and integral multiples of the oscillator cavity transit time. This periodicity was investigated for perspex, C, Al, Cu, Fe and Ta targets, but no systematic variation with target plasma was noted, although two proposed modulation mechanisms^(6,20) do predict an ion mass dependence.

The computed threshold⁽²¹⁾ for stimulated Brillouin back scatter (SBS) is exceeded in the inhomogeneous plasma experiment of Fig. 3 by a factor ≥ 30 , whilst the threshold for Raman sidescatter (SRS) is exceeded marginally. Although no spectral identification was made, it therefore seems reasonable to infer from previous experiments on homogeneous plasmas⁽²²⁾ that the back-scattered radiation peaking at $\theta = 0$ and the beam periphery at $\sim 6.5^\circ$ is indeed SBS from the under dense corona; in the present experiment, however, weak back-scatter from regions very close to the critical surface, rather than noise, should stimulate the Brillouin scatter within the less dense outer regions. The significantly weaker back-scatter signals observed at $\theta \sim 3-5^\circ$ are then consistent with strong resonant absorption at the critical surface, which is expected near these angles. (Since the critical surface may have significant curvatures induced by two-dimensional hydrodynamic expansion and by caviton formation⁽²³⁾ θ has only an averaged spatial, rather than local,

significance).

Temporal modulation of the scattered signal would then arise from the phase relationship between modes in the incident and reflected beams. Weaker modes reflected from the critical surface are not sufficiently intense to stimulate significant scattering from the (more weakly pumped) gain medium. The scattered signal thus carries the integral round-trip transit time periodicity arising from the incident axial-mode structure, but modified by the non-linear amplification. In all the experiments the laser bandwidth $\Delta\omega < (2\pi c/L)$, where L is the plasma inhomogeneity scale-length, and so the SBS instability threshold should be insensitive to $\Delta\omega$; the lower reflectivity observed in the multimode laser experiments may perhaps be explained by postulating that a restricted number of laser modes grow to a limit determined by saturation.

In conclusion, it is noted that absorption in the plane target is typically 92%, that weak back-scattering occurs over a finite spread of angles centred around the incident beam, and that scatter experiments having high azimuthal and angular resolution offer a convenient technique to help elucidate fine-scale structure of the critical surface.

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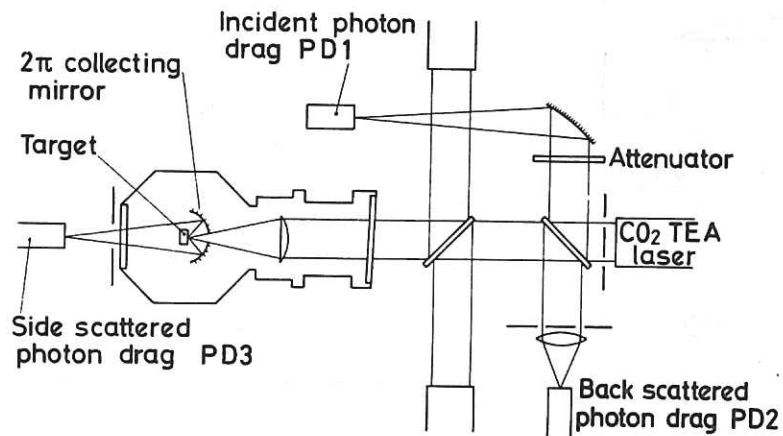


Fig. 1 Experimental layout.

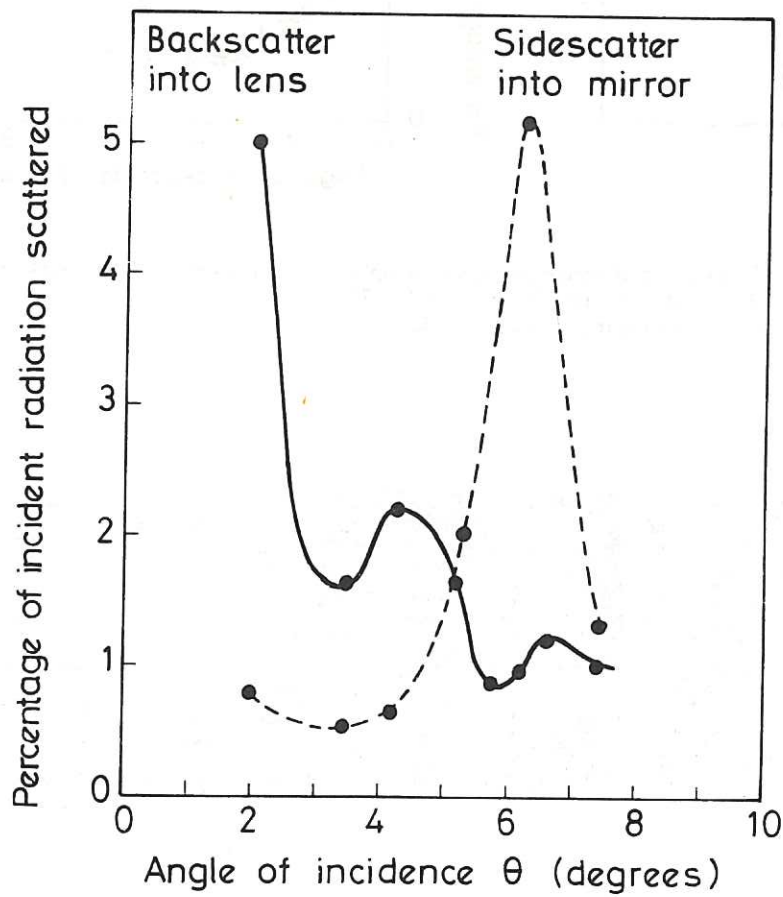
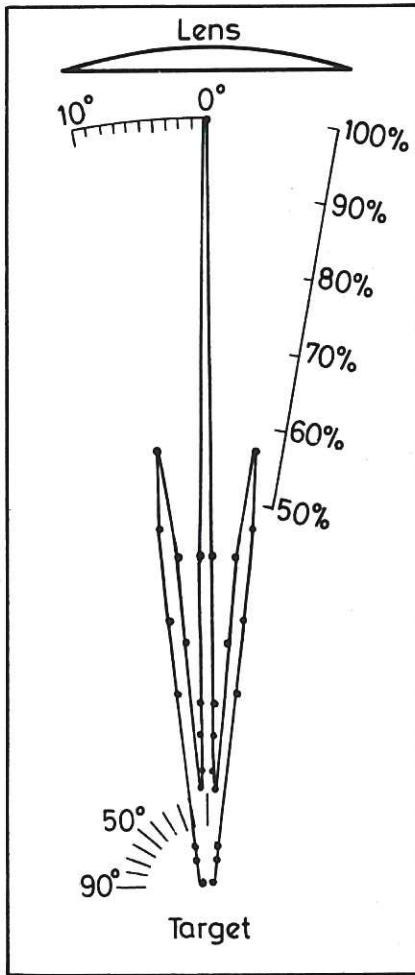


Fig. 2 Variation of total back, and side, scattered radiation with θ .



(a)

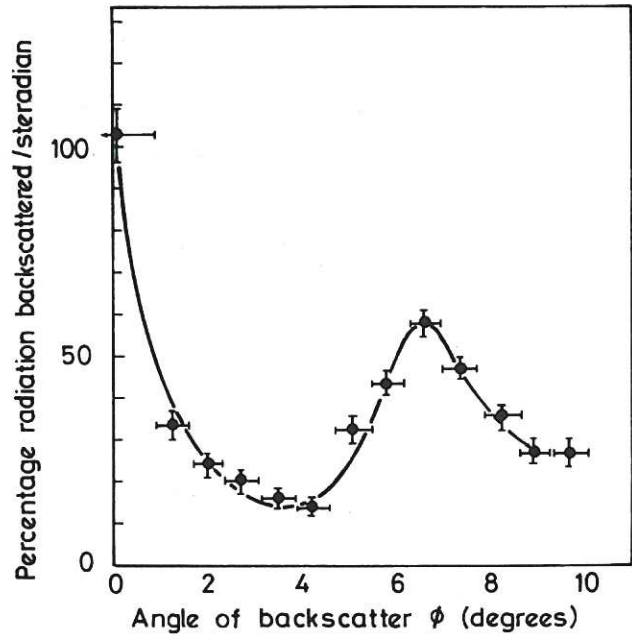
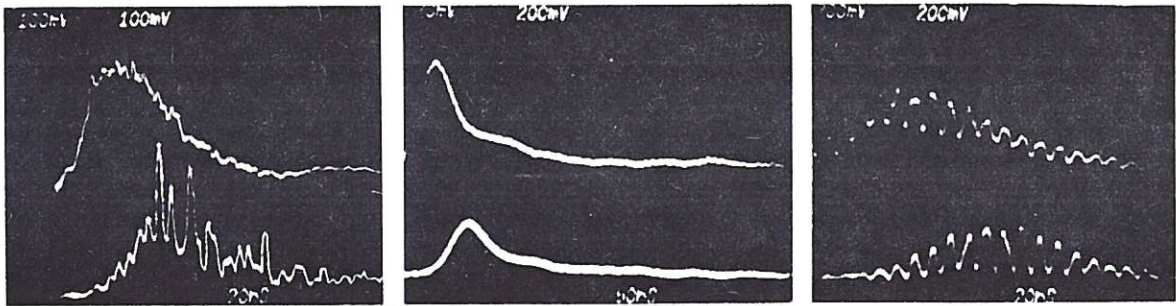


Fig. 3 (a) Polar diagram of scattered radiation per sterad (normalized to axial reflection); incident intensity 10^{13} Wcm^{-2} , $\theta = 0 \pm 7^\circ$.
 (b) Shot to shot error in backscatter data of (a).



(a)

(b)

(c)

Fig. 4 Incident (top) and reflected (bottom) signals for
 (a) $\theta = 4.5 \pm 0.7^\circ$, multimode (b) $\theta = 0 \pm 7^\circ$, single mode and (c) $\theta = 0 \pm 7^\circ$, four axial mode pulses.



The first part of the paper discusses the importance of the research and the objectives of the study. It highlights the need for a comprehensive understanding of the subject matter and the role of the researcher in this process. The second part of the paper focuses on the methodology used in the study, detailing the data collection and analysis techniques. The third part of the paper presents the results of the study, which show a significant correlation between the variables being studied. The final part of the paper discusses the implications of the findings and offers suggestions for future research.

The methodology employed in this study was a combination of qualitative and quantitative approaches. Data was collected through a series of interviews and surveys, which were then analyzed using statistical software. The results of the analysis indicate that there is a strong positive relationship between the variables under investigation. This finding is consistent with previous research in the field and has important implications for practice.

The implications of the study are far-reaching, as they provide valuable insights into the underlying mechanisms of the phenomenon being studied. These findings can be used to inform policy decisions and to guide the development of interventions. Furthermore, the study highlights the need for continued research in this area, as there are still many unanswered questions that need to be addressed.

In conclusion, this study has made a significant contribution to the understanding of the subject matter. The findings are both novel and important, and they have the potential to make a real difference in the world. The study also demonstrates the value of a rigorous and systematic research process, and it serves as a model for other researchers in the field.

The author would like to thank the following individuals for their support and assistance during the course of the study: [Name], [Name], and [Name]. The author also wishes to express their appreciation to the funding agency for their generous contribution to the research.

The first part of the document discusses the importance of maintaining accurate records of all transactions. It emphasizes that every entry, no matter how small, should be recorded to ensure the integrity of the financial statements. This includes not only sales and purchases but also expenses and income. The text suggests that a systematic approach to record-keeping is essential for identifying trends and making informed decisions.

In the second section, the author explores various methods for organizing financial data. One key recommendation is the use of clear, descriptive labels for each entry to avoid confusion. Additionally, the importance of regular reconciliation is highlighted, as it helps to catch errors early and ensures that the books are balanced. The text also touches upon the benefits of using accounting software, which can streamline the process and reduce the risk of human error.

The final part of the document provides practical advice on how to handle common accounting challenges. It discusses the importance of staying up-to-date with changes in tax laws and regulations, as well as the need for professional assistance when dealing with complex transactions. The author concludes by encouraging a proactive approach to financial management, suggesting that regular reviews and adjustments are necessary for long-term success.