Effect of Overlapping Laser Beams and Density Scale Length in Laser–Plasma Instability Experiments on OMEGA EP

M. J. Rosenberg,[1] A. A. Solodov,[1] J. F. Myatt,[2] S. Hironaka,[2] J. Sivajeyan,[2] R. K. Follett,[1] T. Filkins,[1] A. V. Maximov,[1] C. Ren,[1,3,4] S. Cao,[1,3] P. Michel,[5] M. S. Wei,[1] J. P. Palastro,[1] R. H. H. Scott,[6] K. Glize,[6] and S. P. Regan[1]

[1]Laboratory for Laser Energetics, University of Rochester
[2]Department of Electrical and Computer Engineering, University of Alberta
3Department of Mechanical Engineering, University of Rochester
[4]Department of Physics and Astronomy, University of Rochester
[5]Lawrence Livermore National Laboratory
[6]Central Laser Facility, STFC Rutherford Appleton Laboratory

Laser–plasma instabilities (LPI's) are a concern in inertial confinement fusion (ICF) experiments because of the reduction in laser energy and potential generation of hot electrons, which can limit compression of the imploding capsule. Stimulated Raman scattering (SRS) and two-plasmon decay (TPD) can occur at densities at and below the quarter-critical density of the laser [$n_e = n_c/4$, where n_e is the electron density and n_c is the critical density for the laser wavelength λ_0 (in μm) (with $n_c \approx 1.1 \times 10^{21}\,\lambda_0^{-2}$ cm^{-3}), and have been observed at ICF-relevant intensities. Understanding these instabilities and their dependence on density scale length and overlapping laser beam geometry is critical to the pursuit of ICF ignition and fusion gain.

Planar- and spherical-geometry experiments were conducted on OMEGA EP to systematically explore SRS and TPD at scale lengths intermediate between previous experiments, at shorter scale length on OMEGA and longer scale length at the National Ignition Facility (NIF), and with different overlapped laser geometry. Solid 700-μm-diam CH spheres and 250-μm-thick CH slabs were irradiated with one or four beams and 750-μm spot size or with one beam and a 400-μm spot in a 2-ns square pulse or 4-ns ramp pulse with total laser energy of 8.2 to 9.3 kJ.

Figure 1 shows the 2-D *DRACO*-simulated quarter-critical density scale length, temperature, intensity, and threshold parameters for SRS and TPD for four-beam planar [Figs. 1(a)–1(d)] and spherical experiments [Figs. 1(e)–1(h)] with 750-μm phase plates and a 2-ns square pulse. Planar four-beam experiments were predicted to reach density scale lengths on axis of around 300 μm, electron temperatures of 2.8 keV, and overlapped laser intensities of 8×10^{14} W/cm^2. In contrast, four-beam spherical experiments were predicted to reach scale lengths of only 150 μm and similar electron temperatures (2.7 keV) and overlapped laser intensities (8.5×10^{14} W/cm^2). Planar one-beam experiments with the 750-μm spot had reduced intensity, temperature, and scale length, while one-beam experiments with the 400-μm spot size had a 190-μm scale length and laser intensity (4×10^{14} W/cm^2) between the 750-μm one-beam and four-beam experiments.

Time-resolved scattered-light spectra between wavelengths of 400 and 750 nm were measured for a variety of experiments driven by the 2-ns square pulse, as shown in Fig. 2. TPD is evident in a doublet feature corresponding to half-harmonic ($\omega/2$) emission around 702 nm, while SRS appears as a singlet red-shifted $\omega/2$ feature from absolute backscatter at quarter-critical density or as a broad-wavelength feature <680 nm generated in the underdense region. TPD is most prominent in the four-beam planar and spherical experiments, while SRS is generally favored in one-beam experiments, especially at high intensity with the small distributed phase plates (DPP's).

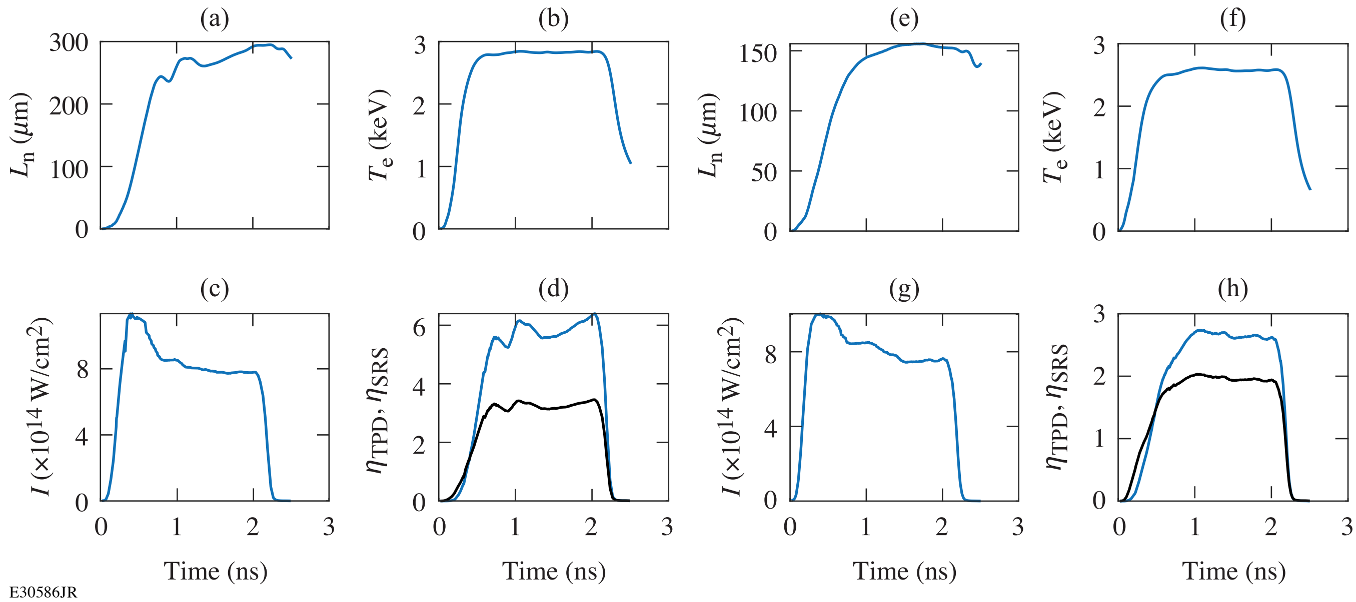

Figure 1
Two-dimensional *DRACO*-simulated plasma conditions at the quarter-critical density along the axis of symmetry for [(a)–(d)] a planar experiment and [(e)–(i)] a spherical experiment, driven by four beams in a 2-ns square pulse. The [(a),(e)] density scale length, [(b),(f)] electron temperature, [(c),(g)] overlapped laser intensity, and [(d),(h)] SRS (blue curves) and TPD (black curves) threshold parameters η are shown.

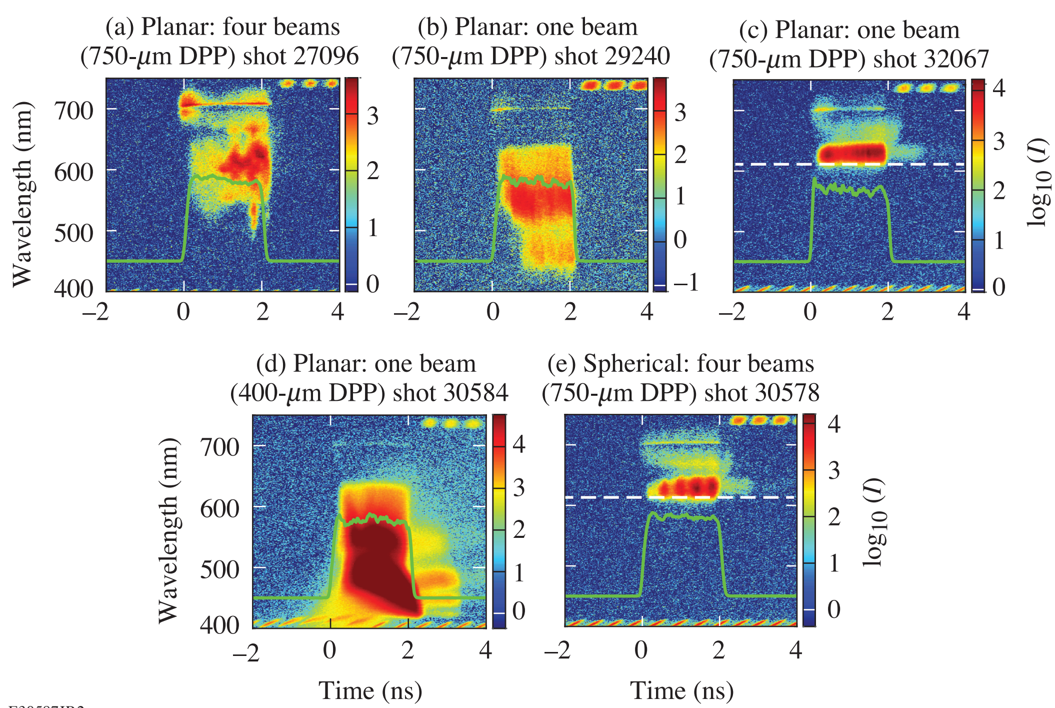

Figure 2
Measured time-resolved scattered-light spectra for experiments with a 2-ns square pulse (green line) and (a) a planar target irradiated by four beams, [(b),(c)] a planar target irradiated with one beam with a 750-μm spot size, (d) a planar target irradiated by one beam with a 400-μm spot size, and (e) a 700-μm-diam spherical target irradiated by four beams. [(c),(e)] The dashed white line represents the 630-nm cutoff of a long-pass filter, with (b) showing data from a nominally identical experiment as (c), but without the long-pass filter. The green line represents the laser pulse. The signal is strongly saturated in the 450- to 550-nm range in (d). Different neutral density filters and sub-aperture backscatter diagnostic throughput for each shot limits comparison of absolute signal levels.

Comparison to previous experiments on OMEGA[1] and the NIF[2] elucidate the effect of scale length and single-beam versus overlapped laser intensity on the prevalence of SRS and TPD. Typical OMEGA 60-beam spherical experiments at ~150-mm scale length and low (<10^{14} W/cm^2) single-beam intensity show evidence only of TPD and not SRS. Planar and spherical experiments at ~400- to 600-μm scale length on the NIF are dominated by SRS and show negligible TPD. In combination with these experiments on OMEGA EP, it is evident that shorter density scale lengths and lower single-beam intensities (at sufficient overlapped intensity) are relatively favorable for TPD, while longer density scale lengths and higher single-beam intensities are relatively more favorable for SRS. These results are generally consistent with absolute TPD and SRS threshold considerations and the prevailing theory that TPD is more of a multibeam instability than SRS. This work will contribute to LPI mitigation techniques for direct-drive ICF.

This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0003856, the University of Rochester, and the New York State Energy Research and Development Authority.

1. W. Seka *et al.*, Phys. Plasmas **16**, 052701 (2009)
2. M. J. Rosenberg *et al.*, Phys. Rev. Lett. **120**, 055001 (2018); M. J. Rosenberg *et al.*, Phys. Plasmas **27**, 042705 (2020).