Unabsorbed Light Beamlets for Diagnosing Coronal Density Profiles and Absorption Nonuniformity in Direct-Drive Implosions on OMEGA

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Laser-direct-drive implosions require spherically symmetric compression to avoid low-mode asymmetries and hydrodynamic instabilities.[1,2] Absorption efficiency is known to be severely degraded by cross-beam energy transfer (CBET),[3,4] and scattered-light observations with the diagnostic described in this summary have revealed significant asymmetry during OMEGA implosions. The most-direct diagnostic for laser absorption is the light scattered from the implosion. Isolating the unabsorbed light from each individual OMEGA beam using the 3ω gated optical imager (GOI) diagnostic[5] has facilitated our understanding of the effect that CBET and other physics have on absorption.

The imaged scattered light appears as a pattern of distinct spots, each corresponding to a single beam (Fig. 1). Each spot can be thought of as the end of a "beamlet"—a small component of the beam originating from a specific point in the beam's far-field spatial profile and following a path through the plasma determined by refraction. The intensity of the beamlet varies along its path due to absorption and CBET until it exits the plasma and ultimately reaches the diagnostic. An important component of the 3ω GOI is a Wollaston prism that splits the collected light into orthogonal polarization components, resulting in two separate beamlet spot images at every camera exposure time.

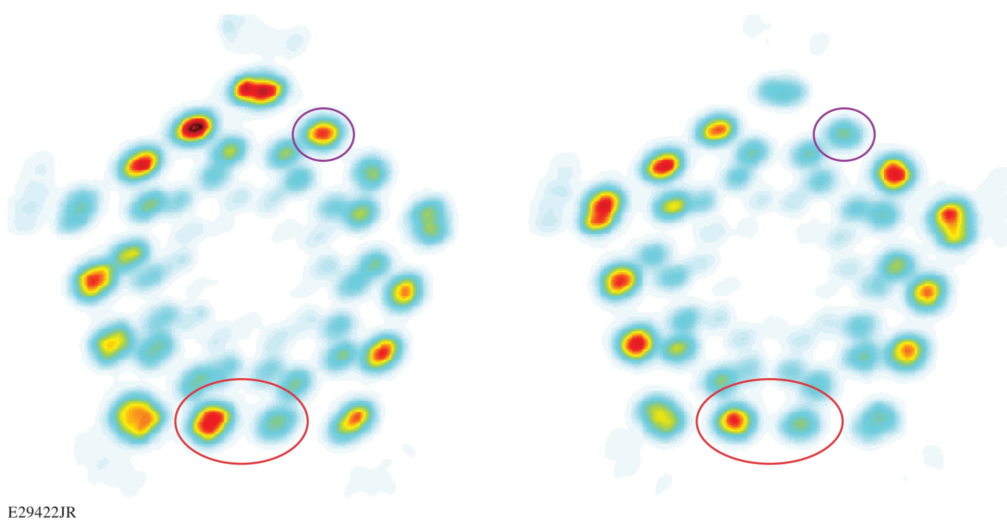

Figure 1
3ω GOI beamlet images collected during an OMEGA implosion for two orthogonal polarizations. The magenta circles highlight a beamlet that is strongly polarized. The red ovals highlight two beamlets that are in the same angular group but clearly have much different intensities.

In a symmetric implosion, all beamlets collected from beams at the same angular distance from the diagnostic should have traveled equivalent paths. With polarization smoothing, each beamlet in the group will have identical CBET and absorption along their paths. All spots in the group are expected to have similar intensities and be equally split between the two orthogonal polarization sub-images. Diagnostic images show that neither of these assumptions is true (Fig. 1). Nonuniformities in the scattered light from an implosion suggest that corresponding nonuniformities may occur in the laser absorption that could severely impact implosion performance. The nonuniformity is believed to be a result of the effect of CBET on the polarization smoothing method used by OMEGA.[6]

The positions of the beamlet spots in the images are determined by the refraction of each beamlet though the plasma and can be used as a density profile diagnostic. In Figs. 2(a)–2(c), the measured beamlet radii are compared to predictions using ray tracing through density profiles calculated by the *LILAC* code using three different physics models. The outer spot positions are most sensitive to the model used. The flux-limited no-CBET[7] model does not predict spot locations for the outer beam groups similar to those measured [Fig. 2(a)]. The Goncharov nonlocal electron transport model[8] is better at predicting the actual spot positions [Fig. 2(b)], and the match is further improved [Fig. 2(c)] when a CBET model is included. Least-square fitting of the density profile was performed to find the best fit to the measured spot positions and to gain further insight into the accuracy of the density profile modeling. The best fits suggest that even the Goncharov/CBET model underpredicts the plasma density farther out in the corona [Fig. 2(d)].

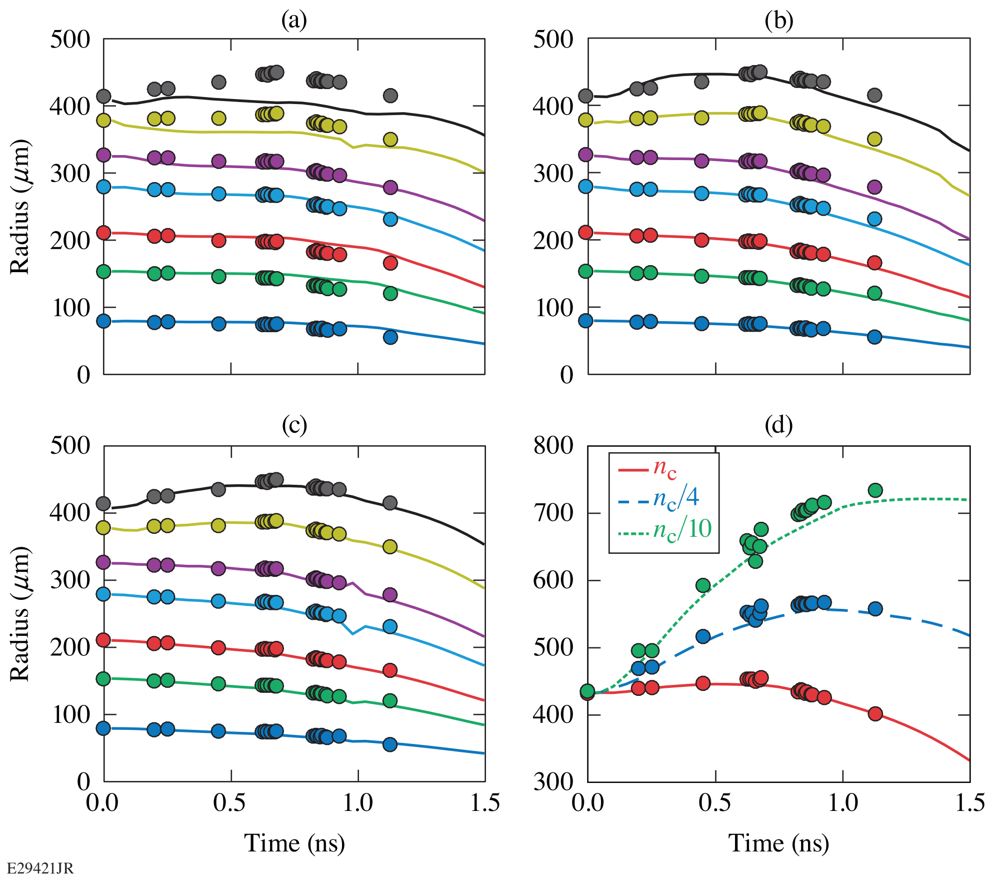

Figure 2
A comparison between the measured beamlet radii (circles, each beam group in a different color) and the predictions using ray tracing through the coronal plasma density profiles (curves) predicted using different physics models: (a) flux-limited ($f = 0.06$) electron heat transport, no CBET; (b) Goncharov nonlocal electron heat transport, no CBET; and (c) Goncharov nonlocal electron heat transport with CBET. (d) Predictions using the same model as in (c) for the time-varying positions of the plasma critical density (n_c) radius, along with the $n_c/4$ and $n_c/10$ surfaces (curves). The circles show the surface radii given by a best fit to the actual measured spot positions.

The 3ω GOI diagnostic was used in conjunction with the wavelength-tunable TOP9 laser[9] to measure the effect of wavelength detuning on CBET.[10] TOP9 appears in the 3ω GOI image as an additional spot. The intensity of the TOP9 beamlet depends strongly on CBET with the other beams. Shifting the TOP9 wavelength with respect to the OMEGA beams alters the magnitude (and even the direction) of energy exchange between TOP9 and the other OMEGA beams. Figure 3(a) shows the predicted TOP9 beamlet intensity versus the wavelength detuning (solid red curve). The measured TOP9 beamlet intensity [Fig. 3(a), magenta circles] supports these predicted trends in general but not in all of the specific details. Since polarization smoothing was used on TOP9, the beamlet polarization was predicted to always be at 45°, but the measurements show significant polarization variation [Fig. 3(b)]. Like the implosion nonuniformity discussed above, these discrepancies may be due to the polarization smoothing method used on OMEGA.

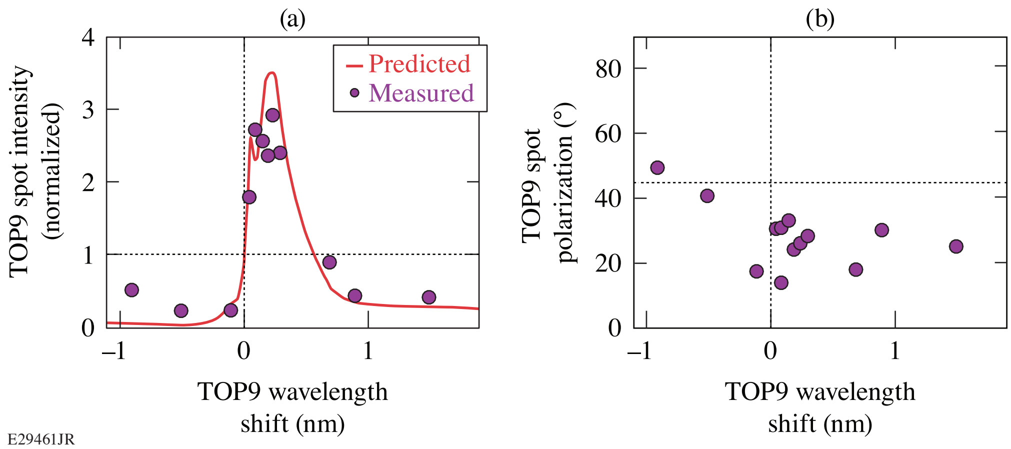

Figure 3
(a) Intensity of the TOP9 beamlet and (b) polarization of the TOP9 beamlet versus the wavelength shift of the TOP9 beam with respect to the 60 OMEGA beams. Predicted intensity was normalized to the intensity when $\Delta\lambda = 0$ and the uncalibrated measured intensity is arbitrarily scaled to match the predicted range.

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1. S. E. Bodner *et al.*, Phys. Plasmas **5**, 1901 (1998).
2. S. Skupsky and R. S. Craxton, Phys. Plasmas **6**, 2157 (1999).
3. W. L. Kruer *et al.*, Phys. Plasmas **3**, 382 (1996).
4. C. J. Randall, J. J. Thomson, and K. G. Estabrook, Phys. Rev. Lett. **43**, 924 (1979).
5. D. H. Edgell *et al.*, Rev. Sci. Instrum. **89**, 10E101 (2018).
6. D. H. Edgell *et al.*, "Low-Mode Asymmetry due to Polarization Smoothing in OMEGA Implosions," to be submitted to Physical Review Letters.
7. R. C. Malone, R. L. McCrory, and R. L. Morse, Phys. Rev. Lett. **34**, 721 (1975).
8. V. N. Goncharov *et al.*, Phys. Plasmas **15**, 056310 (2008).
9. B. E. Kruschwitz *et al.*, Proc. SPIE **10898**, 1089804 (2019).
10. D. H. Edgell *et al.*, Phys. Plasmas **24**, 062706 (2017).