Validating Heat-Transport Models Using Directly Driven Spheres on OMEGA

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The indirect-drive approach to inertial confinement fusion (ICF) uses lasers to heat a radiation oven, or hohlraum. The radiation drive ablatively implodes a capsule filled with deuterium and tritium. Hohlraums are notoriously difficult to simulate due to the complex interplay of difficult-to-model physical processes. These processes include radiation and atomic physics, which generate the x-ray drive; laser–plasma interactions, which govern how the laser couples to the hohlraum; and heat transport, which determines how energy is partitioned. Further, integrated simulations of both a hohlraum and a capsule almost universally predict a capsule "bang time" earlier than observed, colloquially referred to as the "drive deficit."[1,2]

The hohlraum modeling framework has been developed over the years through simpler experiments, e.g., gold disk emission experiments,[3] vacuum hohlraums,[4] and gold sphere experiments.[5] As a natural development of this effort, recent experiment and simulation work has been performed to isolate the effect of heat transport using a directly driven, solid beryllium sphere.[6] These experiments were fielded on the OMEGA Laser System and utilized the state-of-the-art optical Thomson-scattering (OTS) and laser-coupling diagnostics. The OTS diagnostic precisely measured plasma conditions, and the laser coupling gave an accurate assessment of scattered laser energy, which is important for understanding the energy partition within the system. Comparisons to 2-D *LASNEX* simulations showed striking agreement with the data as long as certain heat-transport models were chosen.

The OTS measurements rely on the state-of-the-art fourth-harmonic Thomson-scattering diagnostic developed at LLE. Use of a 263-nm probe beam expands the range of accessible plasma conditions, enabling the study of high-density plasmas. This introduces technical challenges, however, because it places the spectrum in the ultraviolet range. Broadband imaging in this spectrum is notoriously difficult due to the limited number of transparent glass types available and their rapidly varying index of refraction. To overcome these issues, the Thomson-scattering diagnostic on OMEGA was upgraded in 2012 to a fully reflective optical system that delivers achromatic, diffraction-limited imaging performance across a broad spectral range.[7] Two streak-camera–coupled spectrometers simultaneously record scattered light from fluctuations within the plasma, providing a highly resolved measurement of the complete Thomson-scattered spectrum. Improved spatial resolution allows one to precisely define the volume of plasma sampled, enabling the proper treatment of spatial gradients in the data analysis.

The Thomson-scattering technique allows experimenters to measure key parameters characterizing the experimental plasma, such as the density and temperature. Figure 1 shows the spectrum of scattered light that is determined by the underlying, thermally excited plasma fluctuations. To extract measurement of the plasma parameters, the recorded spectrum must be fitted using a theoretical model that describes the relative amplitudes and phase velocities of these fluctuations. Analysis is complicated by the presence of strong plasma emission and spatial gradients within the plasma. To produce accurate and consistent results, an improved fitting framework was developed that properly accounted for these effects. This resulted in precise, quantitative measurements of the temporal evolution of the plasma temperature and density, which can be directly compared to simulations.

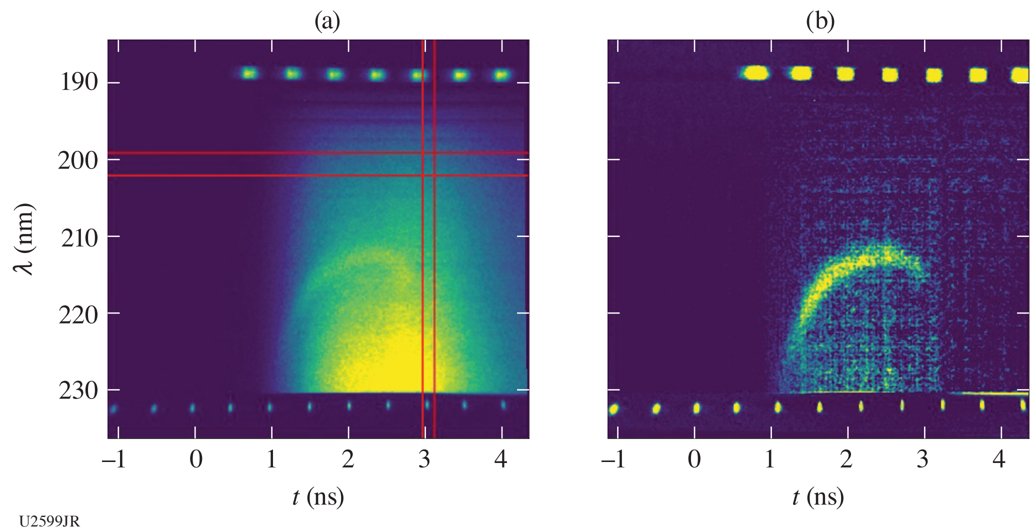

Figure 1
Scattered light observed by the OTS measurement. The vertical and horizontal axes correspond to time and wavelength, respectively: (a) with background and (b) with background subtracted. The bright spectral feature can be used to determine plasma conditions within the probe volume.

The uncoupled laser light was measured using the scattered-light calorimeters and spectrometers on OMEGA. The offline absolutely calibrated calorimeters give the total time-integrated uncoupled light, while the time-varying history of the unabsorbed light is recorded by the spectrometer streak camera. Multiple channels are averaged for each measurement. Two drive intensities were used (10^{14} W/cm^2 and 2.5×10^{14} W/cm^2), and the diagnostics measured 3% and 10% scattered light for the low and high drive intensities, respectively.

Two-dimensional simulations that included the Thomson probe beam were performed in *LASNEX* using three commonly used heat-transport models as shown in Fig. 2. Remarkable agreement with the measurement is obtained with the nonlocal model (dashed curve in the plots), which agrees so well in panel (b) that the dashed curve is obscured by the measured data. Simulations

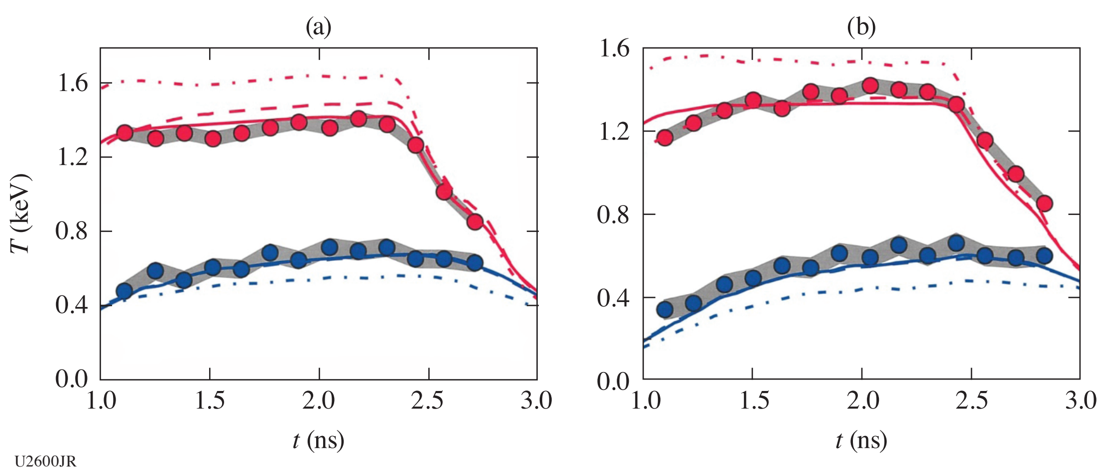

Figure 2
Comparisons of measured and simulated temperatures with nominal intensity of 2.5×10^{14} W/cm^2. (a) and (b) correspond to two different probe positions. Measurement is given by the circles, and the three models—(a local heat-flux model, a nonlocal heat-transport model, and a restricted heat-flux model)—are given by the solid, dashed, and dashed–dotted curves, respectively.

predicted that the scattered light was typically only 1% of the incident power, which does not match the measurement. The agreement with the plasma conditions suggests that heat transport is being modeled correctly and that deficiencies in modeling are in other processes. The understanding developed here is being applied to gold sphere experiments and will ultimately feed into progress toward a more-predictive hohlraum model.

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