LALP-95-158

PHYSICS DIVISION TECHNOLOGY REVIEW

The Role of Symmetry in Indirect-Drive Laser Fusion

Researchers from Los Alamos and Lawrence Livermore National Laboratory (LLNL) are conducting a series of inertial-confinement-fusion (ICF) experiments aimed at understanding the optimum conditions needed to produce the symmetric implosion of a pearl-sized fusion-fuel capsule and in controlling these conditions in a laboratory environment.

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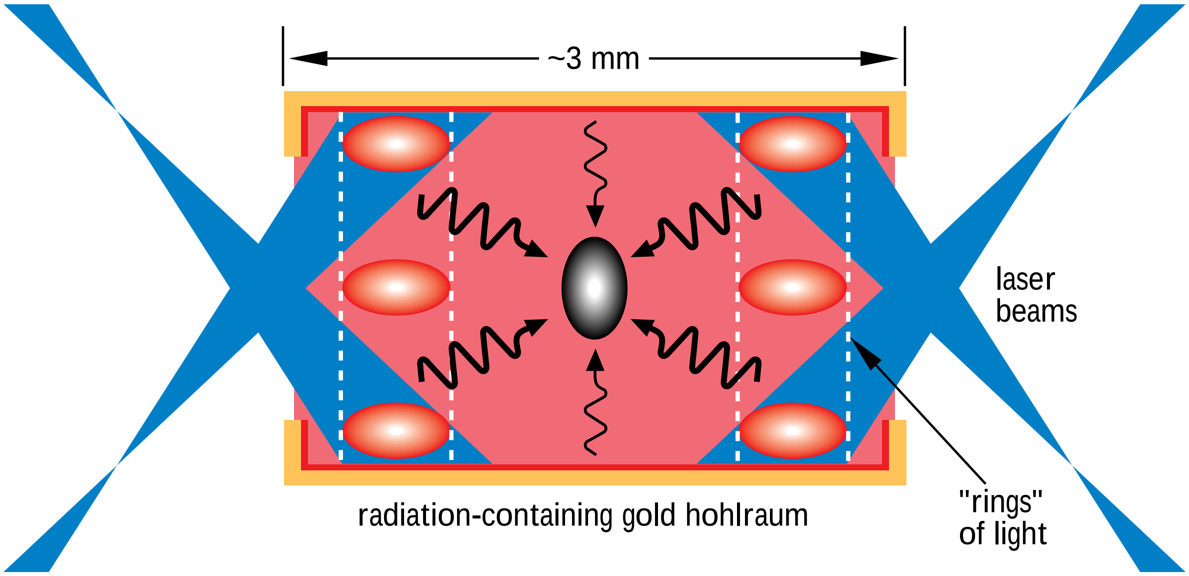

Fig. 1. Oblate geometry as the implosion is driven along the pole of the capsule. The object in the center of the hohlraum depicts the implosion of a fuel-containing capsule.

Thermonuclear fusion, the fundamental energy source of the sun and stars, offers great promise for future energy needs. Achieving sustained thermonuclear fusion in the laboratory, however, requires the production of extremely high temperatures and densities. These conditions, required for igniting fusion, would be produced in high-density, high-temperature implosions driven by lasers or by some form of particle accelerator. These implosions must be driven very symmetrically to be efficient.

Los Alamos in collaboration with LLNL has been pursuing a major study of implosion symmetry using the Nova laser system at LLNL. The experimental and theoretical work in this study will provide crucial input to the design of the proposed National Ignition Facility (NIF), a 192-beam laser. NIF will be a user facility for both ICF ignition experiments and weapons-physics simulations. The ultimate goal of these ICF experiments, however, is the production of cost-effective fusion energy.

The field of ICF is at an exciting threshold because fusion ignition conditions could possibly be achieved in the laboratory (*i.e.*, on the NIF) within the next decade. For maximum energy release, the implosion of the capsule containing the fusion fuel must be symmetric and clean, or without mix, which introduces impurities from the implosion into the fusion fuel. There are two principal approaches to delivering the implosion-driving energy to the capsule. The direct-drive approach applies laser energy directly to the outer surface of the fuel capsule. Indirect drive, the approach that we are currently pursuing, makes use of x-rays produced at the walls of a small cylindrical container known as a hohlraum, which surrounds the fusion fuel capsule.

A typical geometry used in indirect-drive hohlraum experiments is illustrated in Fig. 1. On the Nova laser, five beams enter each side of the hohlraum and form two cones, or rings, of light (shown in red between the dotted lines). The red ovals depict the inner section of individual laser beams with the inner wall of the hohlraum. The regions directly illuminated by the laser (shown in blue) produce a high-temperature plasma, the initial source of x-rays. In the ideal scenario (which ignores a variety of physical effects that can impede the symmetry), these x-rays uniformly fill the hohlraum and are absorbed on the surface of the fuel capsule. The x-rays rapidly heat the surface of the capsule, which vaporizes and expands outward. Reaction forces drive pusher material, which makes up the wall of the fuel capsule, inward. The fuel inside the capsule is compressed and heated, and fusion reactions are produced.

Regardless of how the energy is delivered to the capsule, it must be very uniformly distributed on the surface of the fuel capsule. In other words, there must be excellent drive symmetry for obtaining ignition, *i.e.*, an ICF implosion that releases more energy than is used to cause the implosion. Symmetry tuning (*e.g.*, by varying the position of the laser beams inside the hohlraum) thus becomes an important element in producing a clean implosion. Deviations from spherically symmetric x-ray distributions at the surface of the capsule will be reflected in a characteristic geometrical distortion of the compressed fuel. Figure 1 shows an upright oblate geometry as the implosion is driven more strongly along the pole of the capsule, which is along the hohlraum axis. Figure 2 shows a prolate geometry as the implosion occurs along the capsule's equatorial region. In our current experiments, the imploded fuel capsule is heated to 1 keV. The spatial configuration of the fuel core is assessed by imaging it in self-emission in the 3- to 4-keV spectral range.

Laser-heated hohlraums depart from an ideal blackbody cavity in a number of respects. For instance, a sink of radiation is created by the laser entrance holes. Also, plasma that fills the hohlraum can refract the laser beams or change the position where the hottest sources of x-rays are created. Laser light must be focused in specified, localized regions on the inner surface of the hohlraum so that the light can be efficiently converted to x-rays. Symmetry tuning helps compensate for these effects and produces a more spherically symmetric x-ray pattern at the surface of the capsule. The study of symmetry-tuning methods and measurement techniques has been the principal thrust of this work. The most important measurement method is the detailed analysis of the characteristic distortion of the implosions themselves. In Fig. 3, we illustrate the process of tuning a hohlraum to achieve a highly symmetric drive condition as evidenced by a very round x-ray image of the compressed, imploded core of the resultant implosions. In addition to implosion analysis, other measurement techniques have also been developed that use soft x-ray imaging of the x-ray sources in the hohlraum, observation of re-emission from surrogate targets placed in the hohlraum, and measurement of the shocks created by the radiation field. As a result of this work, a substantial arsenal of measurement methods has been developed and is now ready for use in ignition-level experiments that could be undertaken on the NIF.

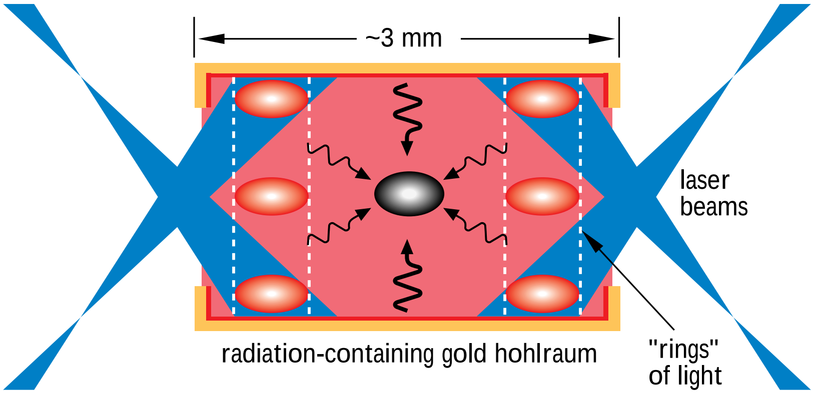

Fig. 2. Prolate geometry as the implosion occurs along the capsule's equatorial region.

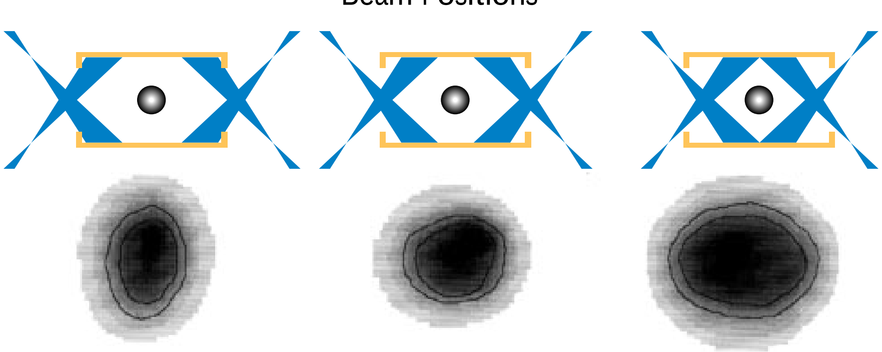

Fig. 3. The process of "tuning" a hohlraum to achieve a highly symmetric drive condition.

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