A first for direct-drive fusion

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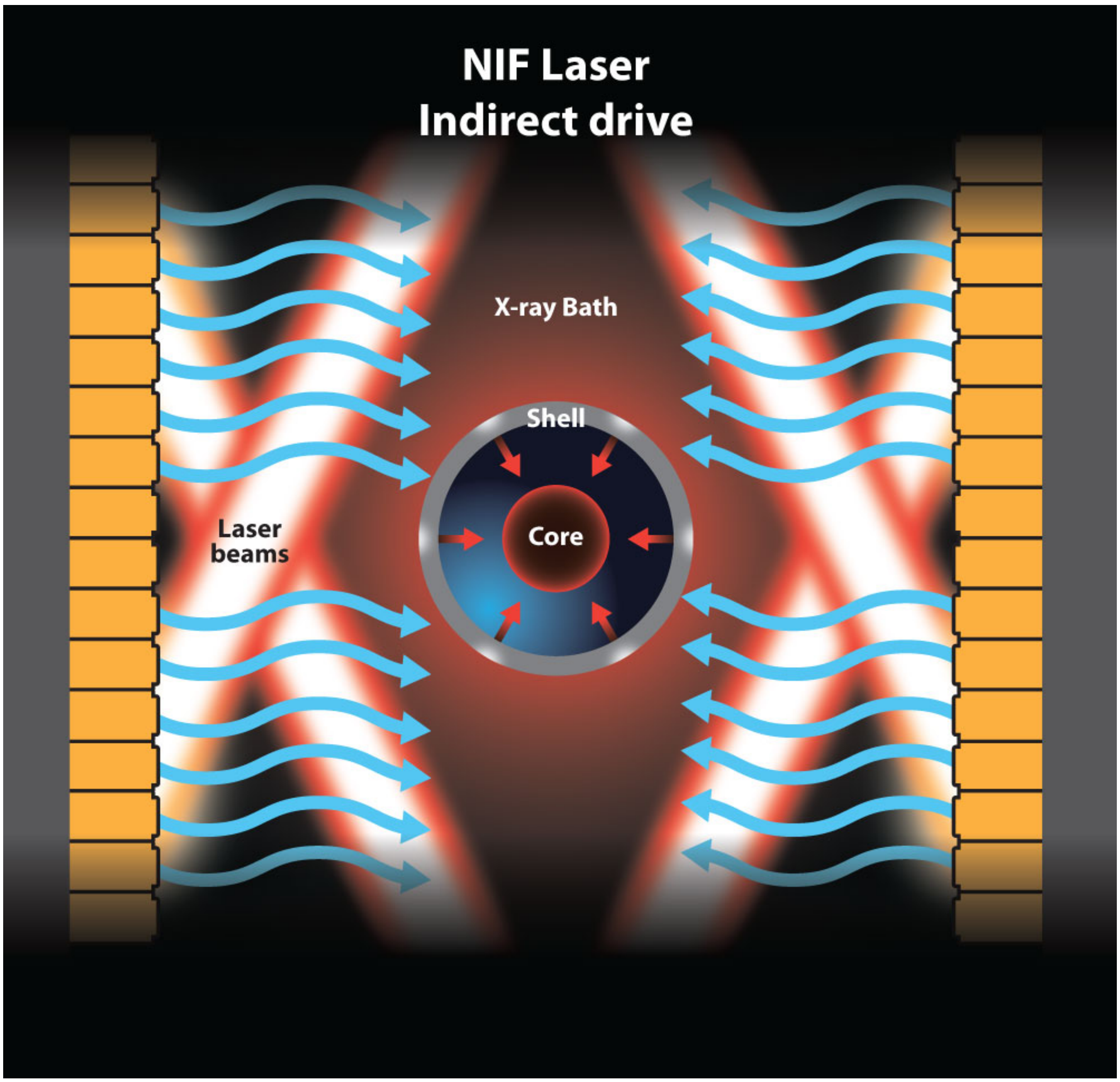


In the indirect-drive method of inertial confinement fusion, laser beams are converted to x-rays. Credit: Michael Osadwic/University of Rochester.

Scientists at the University of Rochester have taken a significant step forward in laser fusion research.

Experiments using the OMEGA laser at the University's Laboratory of Laser Energetics (LLE) have created the conditions capable of producing a fusion yield that's five times higher than the current record laser-fusion energy yield, as long as the relative conditions produced at LLE are reproduced and scaled up at the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory in California.

The findings are the result of multiple experiments conducted by LLE scientists Sean Regan, Valeri Goncharov, and collaborators, whose paper was published in *Physical Review Letters*. Arijit Bose, a doctoral student in physics at Rochester working with Riccardo Betti, a professor of engineering and physics, interpreted those findings in a paper published as Rapid Communications in the journal *Physical Review E (R)*.

Bose reports that the conditions at LLE would produce over 100 kilojoules (kJ) of fusion energy if replicated on the NIF. While that may seem like a tiny flicker in the world's ever-expanding demand for energy, the new work represents an important advance in a long-standing national research initiative to develop fusion as an energy source. The 100 kJ is the energy output of a 100-watt light for about 20 minutes, but in a fusion experiment at NIF, that energy would be released in less than a billionth of a second and enough to bring the fuel a step closer to the ignition conditions.

"We have compressed thermonuclear fuel to about half the pressure required to ignite it. This is the result of a team effort involving many LLE scientists and engineers," said Regan, the leader of the LLE experimental group.

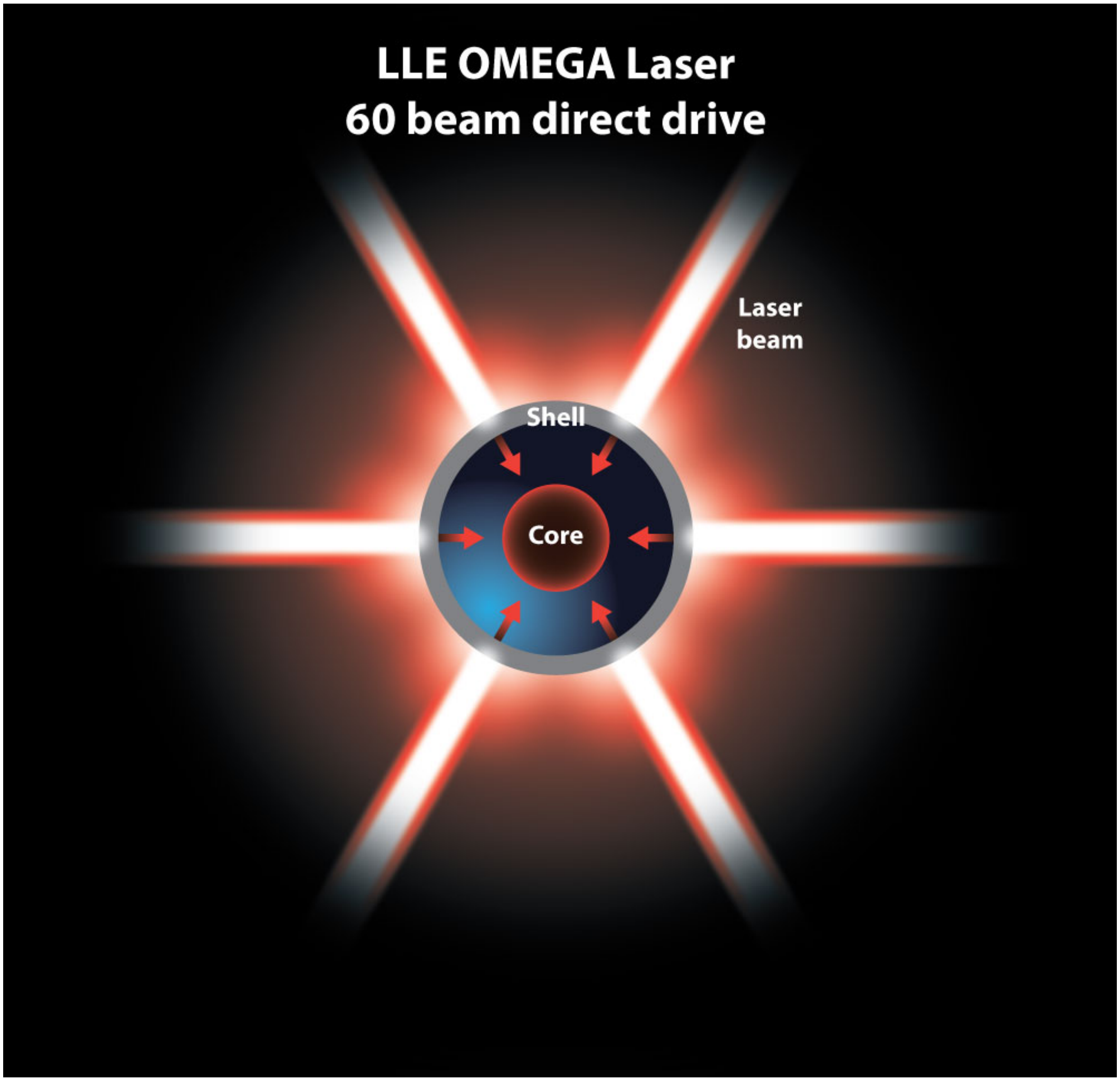
If ignited, thermonuclear fuel would unleash copious amounts of fusion energy, much greater than the input energy to the fuel.

"In laser fusion, an ignited target is like a miniature star of about a 10th of a millimeter, which produces the energy equivalent of a few gallons of gasoline over a fraction of a billionth of a second. We are not there yet, but we are making progress" said Betti, the Robert L. McCrory Professor at the Laboratory for Laser Energetics.

In terms of proximity to the conditions required to ignite the fuel, the two recent LLE papers report that OMEGA experiments match the current NIF record when extrapolated to NIF energies. Igniting a target is the main goal of the laser fusion effort in the United States.

As part of their work, researchers carefully targeted the LLE's 60 laser beams to strike a millimeter-sized pellet of fuel—an approach known as the direct-drive method of inertial confinement fusion (ICF).

The results indicate that the direct-drive approach used by LLE, home to the most prolific laser in the world (in terms of number of experiments, publications, and diversity of users) is a promising path to fusion and a viable alternative over other methods, including that used at NIF. There, researchers are working to achieve fusion by using 192 laser beams in an approach known as indirect-drive, in which the laser light is first converted into x-rays in a gold enclosure called a hohlraum. While not yet achieving ignition, scientists at LLNL and colleagues in the ICF Community have made significant progress in understanding the physics and developing innovative approaches to indirect drive fusion.



In the direct-drive method of inertial confinement fusion directly strike the fuel pellet. Credit: Michael Osadciw/University of Rochester.

"We've shown that the direct-drive method, is on par with other work being done in advancing nuclear fusion research," said Bose.

"Arijit's work is very thorough and convincing. While much work remains to be done, this result shows significant progress in the direct-drive approach, "says Betti.

Research at both LLE and NIF is based on inertial confinement, in which nuclear fusion reactions take place by heating and compressing—or imploding—a target containing a fuel made of deuterium and tritium (DT). The objective is to have the atoms collide with enough energy that the nuclei fuse to form a helium nuclei and a free neutron, releasing significant energy in the process.

In both methods being explored at LLE and NIF, a major challenge is creating a self-sustaining burn that would ignite all the fuel in the target shells. As a result, it's important that enough heat is created when helium nuclei are initially formed to keep the process going. The helium nuclei are called alpha particles, and the heat produced is referred to as alpha heating.

E. Michael Campbell, deputy director of LLE and part of the research team, said the results were made possible because of a number of improvements in the direct-method approach.

One involved the aiming of the 60 laser beams, which now strike the target more uniformly.

"It's like squeezing a balloon with your hands; there are always parts that pop out where your hands aren't," said Campbell. "If it were possible to squeeze a balloon from every spot on the surface, there would be a great deal more pressure inside. And that's what happens when the lasers strike a target more symmetrically."

"If we can improve the uniformity of the way we compress our targets, we will likely get very close to the conditions that would extrapolate to ignition on NIF. This is what we will be focusing on in the near future" says Goncharov, the new director of the LLE theory division.

Two other enhancements were made at LLE: the quality of the target shell was improved to make it more easily compressed, and the diagnostics for measuring what's taking place within the shell have gotten better. Researchers are now able to capture x-ray images of the target's implosion with frame times of 40 trillionths of a second, giving them information on how to more precisely adjust the lasers and understand the physics.

"What we've done is show the advantages of a direct-drive laser in the nuclear fusion process," said Campbell. "And that should lead to additional research opportunities, as well as continued progress in the field."

Bose says the next step is to develop theoretical estimates of what is taking place in the target shell as it's being hit by the laser. That information will help scientists make further enhancements.

Provided by University of Rochester