Research confirms importance of symmetry in pre-ignition fusion experiments

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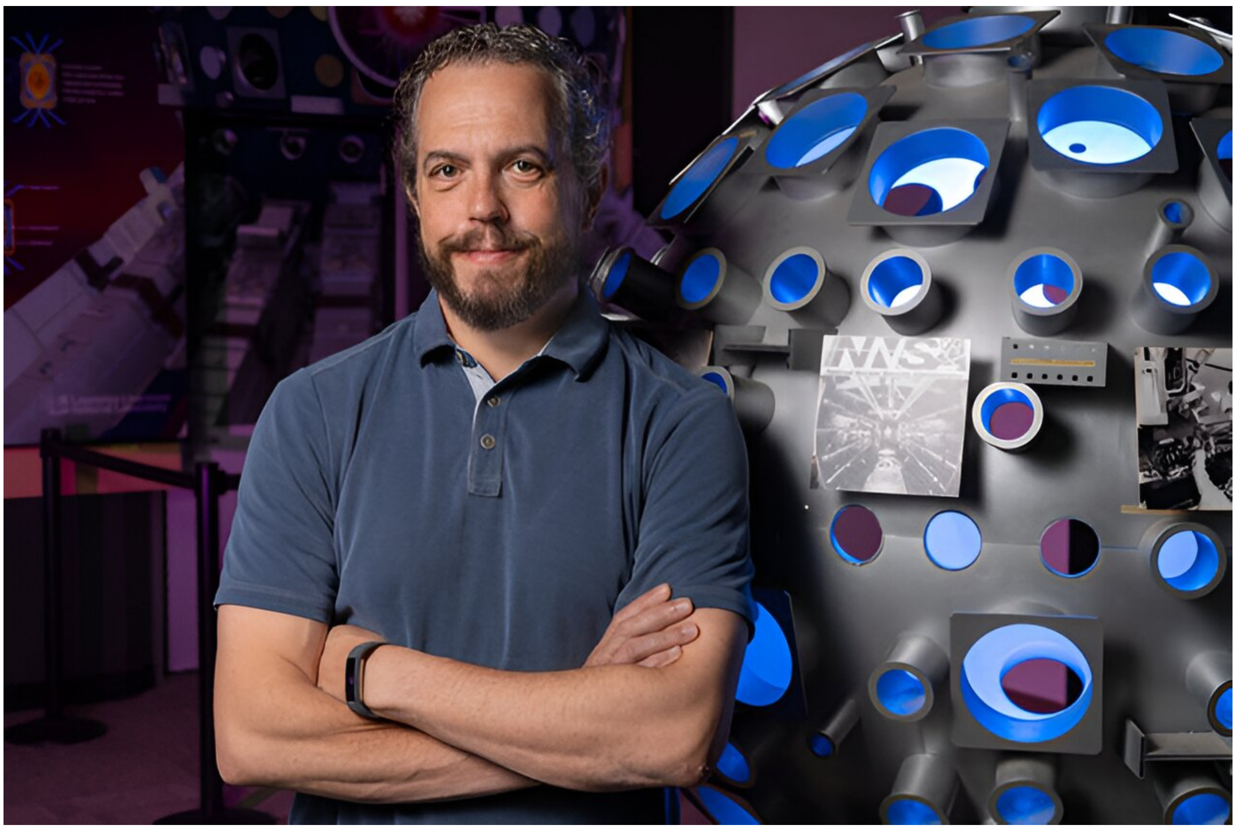

Joe Ralph, co-lead author and inertial confinement fusion research physicist at Lawrence Livermore National Laboratory, discusses the critical role of implosion symmetry in achieving a burning plasma state at the National Ignition Facility. Credit: Blaise Douros/LLNL

Researchers at Lawrence Livermore National Laboratory (LLNL) have retrospectively confirmed that implosion asymmetry was a major aspect of fusion experiments before achieving ignition for the first time at the Lab's National Ignition Facility (NIF), the world's most energetic laser.

The findings were recently detailed in a *Nature Communications* paper titled "The impact of low-mode symmetry on inertial fusion energy output in the burning plasma state." The study was co-led by LLNL inertial confinement fusion (ICF) research physicists Joe Ralph, Steven Ross and Alex Zylstra, the former lead of the Hybrid-E ICF campaign.

In 2021, indirect drive ICF experiments achieved a burning plasma state with neutron yields exceeding 170 kJ, roughly three times the record in 2019 and a necessary stage for igniting plasmas. The results were achieved despite multiple sources of degradations—including asymmetries—that led to high variability in performance. This milestone was a critical step toward achieving ignition on Dec. 5, 2022, Ralph said.

The significance of symmetry in ICF experiments, Ralph said, is like trying to fly an airplane with a heavy left wing. The relative wing weight doesn't matter much while you are still on the ground, but it makes a big difference when you try to lift off. Achieving a burning plasma is like lifting off.

"Reaching a burning plasma state was a pivotal moment for us," Ralph said. "It validated years of theoretical and experimental work and provided a solid foundation for future advancements."

For the first time, the paper presents an empirical degradation factor for mode-2 asymmetry in the burning plasma regime, in addition to previously determined degradations of radiative mix and mode-1 asymmetry. The analysis demonstrates that incorporating these three degradations into the theoretical fusion yield scaling developed in 2017-2018 accounts for the measured fusion performance variability in the two highest-performing experimental campaigns on the NIF to within error.

"In our fusion experiments, achieving symmetry is crucial," Ralph said. "If the plasma is not uniformly compressed, the energy is not efficiently contained, then the performance suffers. By understanding and correcting these asymmetries, we can ensure that the conditions are just right for ignition, much like making sure your airplane is properly balanced before taking off."

The paper highlights how the team quantified the performance sensitivity to mode-2 asymmetry in the burning plasma regime and applied the results, in the form of an empirical degradation factor, to a 1D fusion performance model. Additionally, the team determined through a series of integrated 2D radiation hydrodynamic simulations that the sensitivity to mode-2 was consistent with the experimentally determined sensitivity only when including alpha-heating.

"By isolating and quantifying the mode-2 degradation, we were able to refine our models and improve the accuracy of our predictions," Ralph said. "These findings underscore the importance of continuous refinement and understanding of the variables affecting fusion performance. By identifying and accounting for these degradation factors, we have been better able to assess the performance of our experiments and make more informed decisions. This was a significant step toward achieving ignition."

More information: J. E. Ralph et al, The impact of low-mode symmetry on inertial fusion energy output in the burning plasma state, *Nature Communications* (2024). DOI: 10.1038/s41467-024-47302-8

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