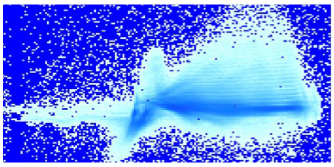

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# Single-Shot Imaging and Phase Retrieval of Void-Shockwave Dynamics in Extreme Conditions

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The recent accomplishment of a 3.88 MJ yield in 2023 along with subsequent successes at the National Ignition Facility (NIF), indicates a transformative era in Inertial Fusion Energy (IFE) research. This milestone showcases nuclear fusion's potential as a sustainable, safe, and virtually inexhaustive source of energy, positioning it as a promising solution to meet the world's growing energy demands. Further improvements to IFE research are dependent on assessing material response during dynamic compression. To address this, our research team is pioneering the imaging of instabilities as fusion capsules collapse. This effort aims to quantify the impact of imperfections in ablator materials during dynamic compression and how it could influence the overall fusion yield. In an experiment conducted at the Matter in Extreme Conditions (MEC) instrument at the Linac Coherent Light Source (LCLS), we employed an x-ray phase-contrast imaging (XPCI) method to accurately measure the capsule's dynamic areal density [1, 2] during this process. To mitigate the effects of random fluctuations of the x-ray free electron laser (XFEL), we implemented a flat-field correction scheme that normalizes the dynamic images, compensating for both XFEL beam inhomogeneities and imperfections accumulated along the x-ray path [3]. For quantitative evaluation, particularly for calculating the phase to determine areal density, we propose two distinct phase retrieval strategies tailored for extracting the phase from a complex, single-shot, multi-material, dynamic image. Our advanced techniques circumvent the typical limitations encountered with conventional phase retrieval methods. These traditional methods often necessitate a single-material composition, require the object to be isolated within the field of view, and are constrained to specific propagation regimes. In contrast, our approaches are not limited to these requirements and can determine the absolute phase, obviating the need for phase unwrapping. This feature is particularly beneficial since large phase excursions are induced by the compressive force of the shock wave in relation to the surrounding material. The first method involves using a single, flat-field corrected dynamic image for phase reconstruction. This method incorporates automatic differentiation (AD) [4, 5] with the transport of intensity equation (TIE), enabling the fine-tuning of specific parameters to best match experimental conditions and optimize the phase result. Further refinement of the reconstructed image is achieved by adopting the method of reconstructing the projected refractive index, a technique validated by Wittwer et al. [6] The second phase retrieval strategy leverages the inherent speckle pattern and phase contrast that naturally emerges during light propagation in the raw dynamic image. This approach avoids the conventional reliance on flat-field correction, but instead utilizes the unaltered data to uncover the phase information [7]. By using the speckle information, we reconstruct the large-scale structures, while propagation allows for the resolution of finer, small-scale features. These techniques represent a significant advancement in dynamic imaging, offering unprecedented clarity and detail in the visualization of material density. Acquiring areal density information is vital, providing insights into the complexities of achieve self-sustaining fusion reactions in current ICF experiments, has the potential to revolutionize experimental compression approaches, and can introduce additional physics to the computational models used in ICF research.

Citations:

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