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Holographic Snapshots of Laser Wakefields[1]

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Tabletop plasma accelerators driven by intense ultrashort laser pulses or charged-particle bunches can now produce GeV-range electron beams and femtosecond x-ray and gamma-ray pulses, providing compact radiation sources for application in medicine, nuclear engineering, materials science and high-energy physics. In these accelerators, electrons surf on >100 GeV/m electric fields (thousands of times stronger than in conventional accelerators) generated within plasma structures (e.g. electron plasma waves, "bubbles" devoid of electrons) propagating behind the driving pulse. Because of their microscopic size and luminal velocity, however, critical features of these structures that determine the energy, energy spread, collimation and charge of the accelerated beam have eluded direct single-shot observation, inhibiting progress in producing high quality beams and in correlating beam properties with wake structure. Here we demonstrate single shot visualization of laser wakefield accelerator (LWFA) structures for the first time, using Frequency Domain Holography (FDH), a technique designed to image structures propagating near light speed. Our holographic "snapshots" capture the evolution of multiple wake periods, and resolve wavefront curvature seen previously only in simulations. These previously invisible features underlie wave breaking, electron injection and focusing within the wake, the key determinants of beam quality. We reconstruct wake morphology in real-time, providing experimental feedback and optimization. Beyond accelerators, we anticipate that FDH will provide an unprecedented visualization and feedback capability for structures created in diverse laser- and particle-plasma interactions, including fast ignition for laser fusion and plasma-based amplification and compresssion of ultra-intense laser pulses.

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