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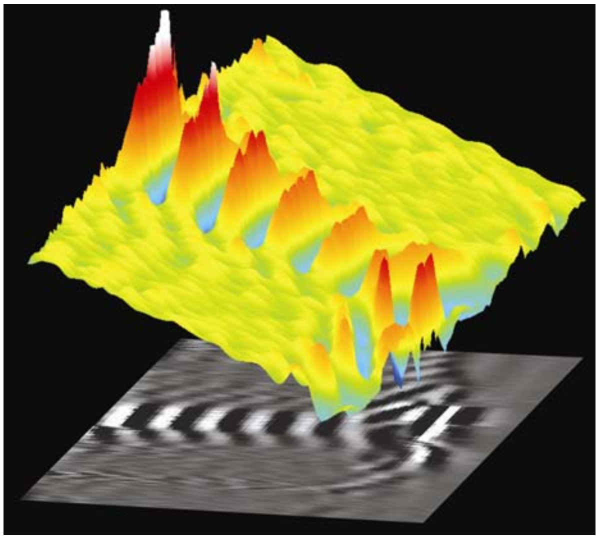
Fastest Waves Ever Photographed

Plasma physicists at the Universities of Texas and Michigan have photographed speedy plasma waves known as Langmuir waves for the first time,[1] using a holographic-strobe camera specially designed for this purpose.

[1] N. Matlis et al., "Snapshots of laser wakefields," to appear in Nature Physics (November 2006)

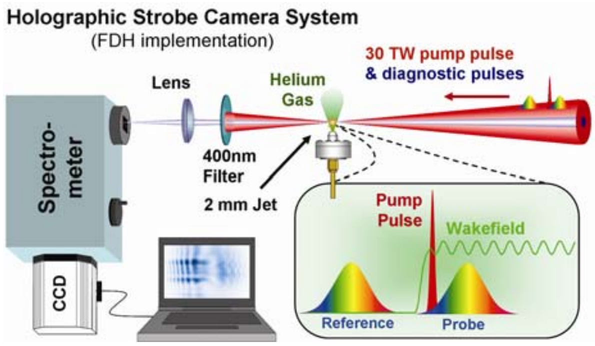


Images of a wakefield produced by a 30 TW laser pulse in plasma of density 2.7 x 10^{18} cm^{-3}. The color image is a 3D reconstruction of the oscillations, and the grey-scale is a 2D projection of the same data. These waves show curved wave-fronts, an important feature for generating and accelerating electrons that has been predicted, but never before seen.

PHILADELPHIA, Pennsylvania, Oct. 30, 2006 – The waves are the fastest matter waves ever photographed, clocking in at about 99.997% of the speed of light, close to *1 billion* miles per hour! But their speed is not their only interesting feature. These waves, known as wakefields because they are generated in the wake of an ultra-intense laser pulse, are traveling oscillations in a sea of electrons known as a plasma, and give rise to enormous electric fields, reaching voltages higher than 100 gigaelectron volts/meter (GeV/m). To understand how strong this is, consider a test electron experiencing one of these electric fields. The electron "surfs" on the electric-field that accompanies the plasma wave, and accelerates almost instantaneously to near-light-speed at a rate of about 2 x 10^{22} m/s^2, which is like going from 0 to 60 mph in one zeptosecond. For those not in the know, that's a billionth of a trillionth of a second, or 1/1,000,000,000,000,000,000,000 of a second! At this rate of acceleration, the electron would outrun any ordinary matter-wave, but the light-speed wakefields keep up, accelerating the electron to relativistic energies.

The ability of these waves to accelerate electrons so strongly has opened up the possibility of creating an ultra-compact version of a high-energy particle accelerator, a device which currently exists only in large-scale facilities like the Stanford Linear Accelerator Center (SLAC) and the International Linear Collider (ILC) at Fermilab in the US, and CERN in Europe. High-energy particle accelerators (which work on the same basic principle as the wakefields, but have electric fields thousands of times weaker) have long been one of our primary resources for learning about the nature of matter, and have on a smaller scale become important as sources of specialized radiation for cancer therapy. But the conventional accelerator technology used to create them, and their enormous size (several miles in length) restricts their existence to only a handful of laboratories around the world, making their use for research or medicine very costly and exclusive. While conventional accelerators such as SLAC and ILC are likely to remain the solution for very high energies, a wakefield-based accelerator could potentially be a thousand times smaller, and would fit on a table-top in a typical hospital or university research lab, providing much greater access to researchers and patients alike.

In spite of vast strides that have recently been made in the development of wakefield technology, there is still much that is unknown about the complex dynamics of the interaction between the wakefields, the accelerated electrons and the ultra-intense laser pulses used to generate them. Until now, a critical element necessary for elucidating the interaction has been missing: the ability to see the waves. Matlis and co-workers have developed a technique called Frequency Domain Holography (FDH) which employs two additional laser pulses propagating with the drive pulse to detect and visualize the wakefield oscillations, enabling researchers to see them for the first time. The pulses are sent into a spectrometer where they interfere holographically and are subsequently analyzed to produce images of the wave structure in real-time, revealing theoretically predicted but never-before-seen features. One important such feature is the curvature of the wave-front, which is a result of relativistic effects, and plays an important role in the generation and acceleration of electron beams with desirable qualities. The ability to photograph these elusive, speedy waves promises to be an important step towards making compact accelerators a reality.



A 30 TW pump pulse at 800 nm (red pulse) focuses into Helium gas driving the generation of the wakefield. A lens, spectrometer and CCD-device act together to form the holographic-strobe camera system. The accompanying two chirped pulses at 400 nm (rainbow pulses) act as the flash bulb to provide illumination.

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Invited Talk:
8:00 AM–9:00 AM, Tuesday, October 31, 2006
Philadelphia Marriott Downtown - Grand Salon A-F
[FR1.00001] **Holographic Snapshots of Laser Wakefields**
http://meetings.aps.org/Meeting/DPP06/Event/52026