Plasma oscillations propel breakthroughs in fusion energy

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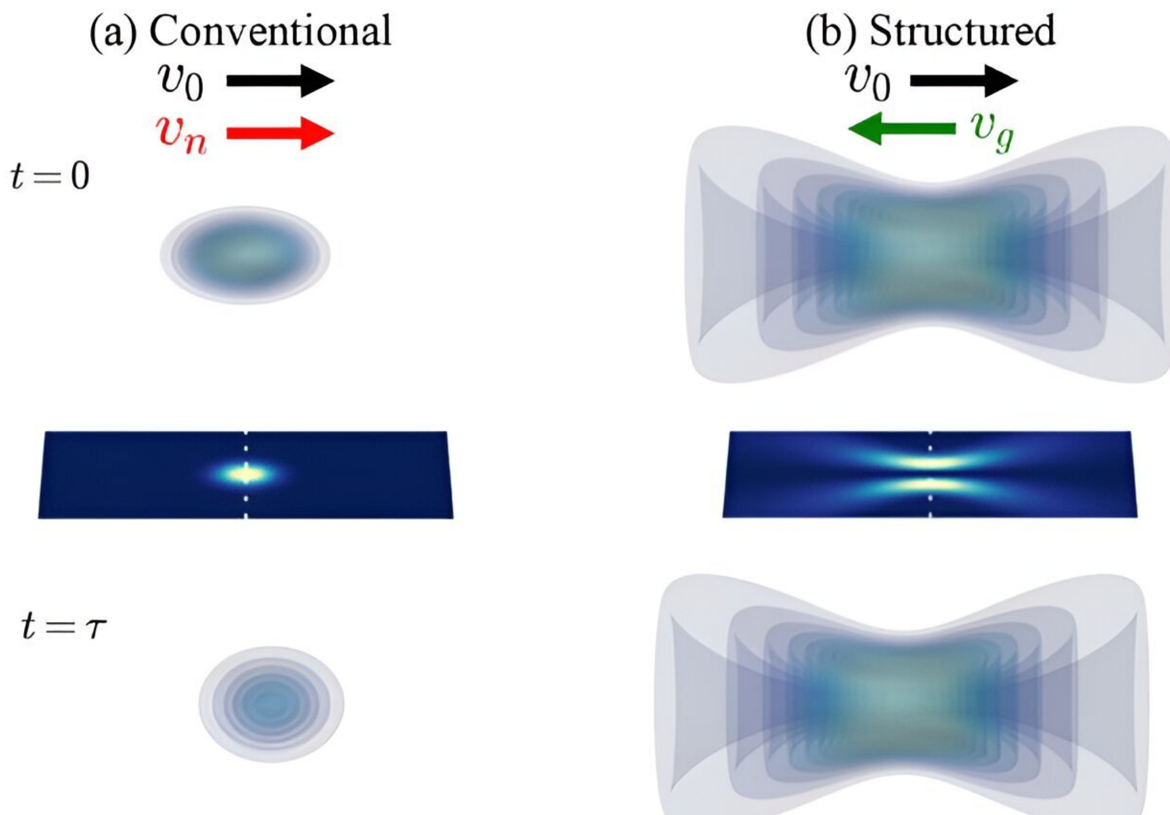

Evolution of the cycle-averaged energy density for a conventional and space-time structured plasma wave. The conventional plasma wave (left) diffracts as it propagates from left to right at a nominal group velocity v_n. The nominal group velocity is determined by the plasma conditions and is parallel to the phase velocity v_0. The peak energy density of the STP (right) travels in the opposite direction as the nominal group velocity and phase velocity while maintaining a constant spatiotemporal profile. Credit: *Physical Review Letters* (2024). DOI: 10.1103/PhysRevLett.132.095101

Most people know about solids, liquids, and gases as the main three states of matter, but a fourth state of matter exists as well. Plasma—also known as ionized gas—is the most abundant, observable form of matter in our universe, found in the sun and other celestial bodies.

Creating the hot mix of freely moving electrons and ions that compose a plasma often requires extreme pressures or temperatures. In these extreme conditions, researchers continue to uncover the unexpected ways that plasma can move and evolve. By better understanding the motion of plasma, scientists gain valuable insights into solar physics, astrophysics, and fusion.

In a paper published in *Physical Review Letters*, researchers from the University of Rochester, along with colleagues at the University of California, San Diego, discovered a new class of plasma oscillations—the back-and-forth, wave-like movement of electrons and ions. The findings have implications for improving the performance of miniature particle accelerators and the reactors used to create fusion energy.

"This new class of plasma oscillations can exhibit extraordinary features that open the door to innovative advancements in particle acceleration and fusion," says John Palastro, a senior scientist at the Laboratory for Laser Energetics, an assistant professor in the Department of Mechanical Engineering, and an associate professor at the Institute of Optics.

Plasma waves with a mind of their own

One of the properties that characterizes a plasma is its ability to support collective motion, where electrons and ions oscillate—or wave—in unison. These oscillations are like a rhythmic dance. Just as dancers respond to each other's movements, the charged particles in a plasma interact and oscillate together, creating a coordinated motion.

The properties of these oscillations have traditionally been linked to the properties—such as the temperature, density, or velocity—of the plasma as a whole. However, Palastro and his colleagues determined a theoretical framework for plasma oscillations where the properties of the oscillations are completely independent of the plasma in which they exist.

"Imagine a quick pluck of a guitar string where the impulse propagates along the string at a speed determined by the string's tension and diameter," Palastro says. "We've found a way to 'pluck' a plasma, so that the waves move independently of the analogous tension and diameter."

Within their theoretical framework, the amplitude of the oscillations could be made to travel faster than the speed of light in a vacuum or come to a complete stop, while the plasma itself travels in an entirely different direction.

The research has a variety of promising applications, most notably in helping to achieve clean-burning, commercial fusion energy.

Co-author Alexey Arefiev, a professor of mechanical and aerospace engineering at the University of California, San Diego, says, "This new type of oscillation may have implications for fusion reactors, where mitigating plasma oscillations can facilitate the confinement needed for high-efficiency power generation."

More information: J. P. Palastro et al, Space-Time Structured Plasma Waves, *Physical Review Letters* (2024). DOI: 10.1103/PhysRevLett.132.095101

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