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First Observation of a One-Way Street at the Plasma Edge

Experiments provide the first laboratory evidence for one-way propagating waves that live at the plasma edge, as predicted by topology.

CHICAGO—Researchers have observed the first laboratory evidence of a topological wave in a plasma—a wave confined to the plasma's edge that travels in only one direction with behavior protected by the geometry of the system. The finding, made in experiments on UCLA's 20-meter-long Large Plasma Device (LAPD), brings a powerful idea from modern mathematics and quantum physics into plasma science. It may ultimately provide new ways to study the hot, difficult-to-access interiors of plasmas and to investigate turbulence at the edge of fusion devices.

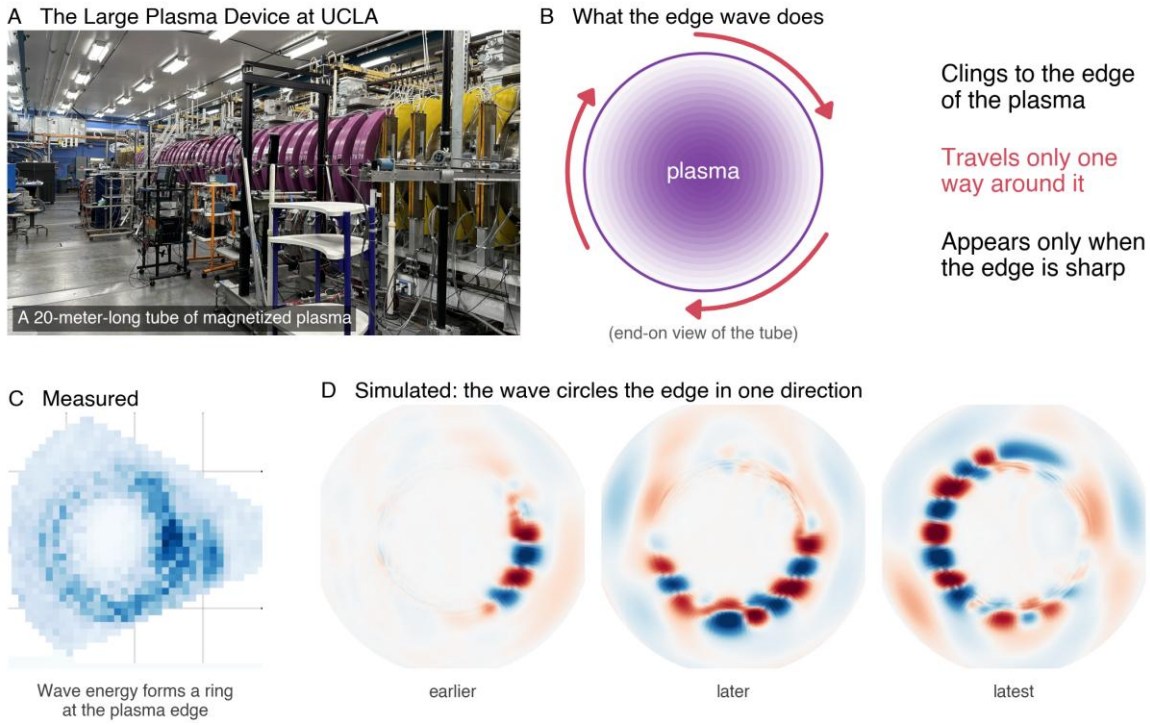


Figure 1: A) The Large Plasma Device at UCLA, where the experiments were performed. (B) Schematic of topological waves, which are trapped at the edge of the plasma and travel around it in only one direction. (C) Measured wave energy in a slice across the plasma column forms a ring at the plasma edge. (D) Three snapshots of the computer simulations of the topological waves, showing the wave moving around the edge in one direction; red and blue colors correspond to the rising and falling of the waves.

Most waves, from ripples in a pond to radio waves from a cell tower, disperse outward from their source and propagate freely. They backscatter when they hit a barrier like a rock. Topological waves, on the other hand, are restricted in where they can exist: they only travel in a fixed direction along the edge of a material, much like cars driving in the outermost lane on a highway. Because of their one-way nature, topological waves cannot easily reflect or scatter, unless there is an abrupt event like a car crash. These exotic features make them ideal for guiding light, sound, and electron flows. First observed in quantum materials (1985 and 2016 Nobel Prize in Physics), topological waves have recently been shown to exist in the Earth's atmosphere [1, 2]: they play an important role in the El Niño Southern Oscillation, which is trapped along the Earth's equator. Now, a team of researchers led by Ziyan Zhu of Boston College have observed topological waves in plasmas, ionized gas containing free-moving electrons, for the first time at the Large Plasma Device (LAPD) (Figure 1) at the University of California, Los Angeles [3].

Topology is a branch of mathematics that describes the properties of shapes that survive smooth deformations such as squeezing and stretching. For example, a donut and a coffee mug have the same topology, because they have the same number of holes and can be smoothly shaped into one another. In contrast, reshaping an orange into a donut requires an abrupt change: punching a hole, which means an orange and a donut have different topology. A change in topology guarantees the existence of a one-way propagating wave at the interface, which may be otherwise forbidden. In a magnetic field, electrons in a plasma move in circles and acquire a different topology than electrons in vacuum. This means that at the boundary where the plasma and vacuum meet, there exist topological waves that have one-way propagation. Members of the team predicted such topological waves in plasmas, called gaseous plasmon polaritons, in 2020 [4, 5]. The team has since been performing experiments at the LAPD to search for these waves and now has evidence for them.

The LAPD is a 20-meter-long cylindrical device wrapped by magnets. The column is 1 meter in diameter and filled with plasma. The plasma density, the concentration of electrons, is highest in the center of the column and drops significantly at the edge of the machine. At the interface, the team creates a sharp density drop that is like a cliff rather than a gentle hill. They then launch microwave bursts into the plasma and use physical probes to detect how the wave propagates. They found that the wave power is concentrated along a ring at each slice of the plasma column, which overlaps with the density drop. They also observed that the waves rotate in a clockwise direction. The appearance of the waves can be controlled by both the microwave frequency and magnitude of the magnetic field, behaviors all consistent with theoretical predictions.

This result establishes plasma as a new experimental platform for topological physics. That matters both for fundamental science and for fusion research. Because the observed edge waves are determined by properties of the plasma as a whole, they may offer a way to infer conditions in the plasma interior—regions that can be too hot for conventional physical probes. The researchers also plan to study whether these robust, one-way waves can interact with or help diagnose edge turbulence, which can degrade confinement in fusion plasmas.

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Abstract

RO06/7 First observation of topological waves in laboratory plasmas
Session RO06: Plasma Waves and Instabilities
9:30 AM–11:54 AM, Friday, November 6, 2026
Room: Hilton Chicago, Salon C 1 & 2, Lower Level

References

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[3] W. Gekelman et al., "The upgraded Large Plasma Device, a machine for studying frontier basic plasma physics," Rev. Sci. Instrum. 87, 025105 (2016).
[4] J. B. Parker, J. B. Marston, S. M. Tobias, and Z. Zhu, "Topological gaseous plasmon polariton in realistic plasma," Phys. Rev. Lett. 124, 195001 (2020).
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