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Until 8 a.m. CDT, Monday, November 2, 2026
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Catching the Wave: Investigating how Magnetic Fields Energize Particles

Some of the most explosive events in the universe depend on interactions taking place on the smallest scales.

CHICAGO—When magnetic fields suddenly rearrange themselves, they can release enormous amounts of energy in a process called magnetic reconnection. This process powers eruptions from the Sun such as solar flares and coronal mass ejections (Figure 1), as well as disturbances in near-Earth space that can produce auroras and, during severe space-weather events, affect satellites and electrical infrastructure.

But there is a fundamental question hidden inside these enormous events: When magnetic energy is released, how does that energy actually reach individual particles?



Figure 1: Magnetic reconnection on the Sun. The rapid rearrangement of magnetic fields releases stored magnetic energy that can energize particles. NASA's Conceptual Image Laboratory

One possible pathway involves plasma waves – oscillations that travel through electrically charged gases (called plasmas), much like waves moving across the surface of the ocean. These waves can transfer energy to electrons moving at similar speeds, energizing them as they "ride" the waves, much like surfers catching ocean waves.

Researchers at West Virginia University have experimentally tracked this pathway. By recreating magnetic reconnection in WVU's PHASMA plasma facility and measuring both plasma waves and the motion of electrons as the event evolved, the researchers observed electrons responding at velocities that matched those of the waves. The researchers used laser-based Thomson scattering to measure how the number of electrons at a given velocity changed over extremely short timescales during magnetic reconnection. At the same time, electrical probes measured plasma waves produced during the event.

The measurements revealed a striking connection: as the plasma wave grew stronger, distinct changes appeared in the electron distribution near specific "wave-matched" electron speeds. When the wave later weakened, these features in the electron population evolved as well.

The result provides direct experimental evidence of a resonant interaction between plasma waves and electrons, a microscopic pathway through which energy released during magnetic reconnection can reach electrons.

"Magnetic reconnection can release a tremendous amount of stored magnetic energy but understanding exactly how that energy reaches individual particles has remained a fundamental problem," said Sonu Yadav of West Virginia University. "Our measurements allow us to watch the plasma wave and the electrons evolve together and see the electron population change at the speeds where the interaction is expected to occur."

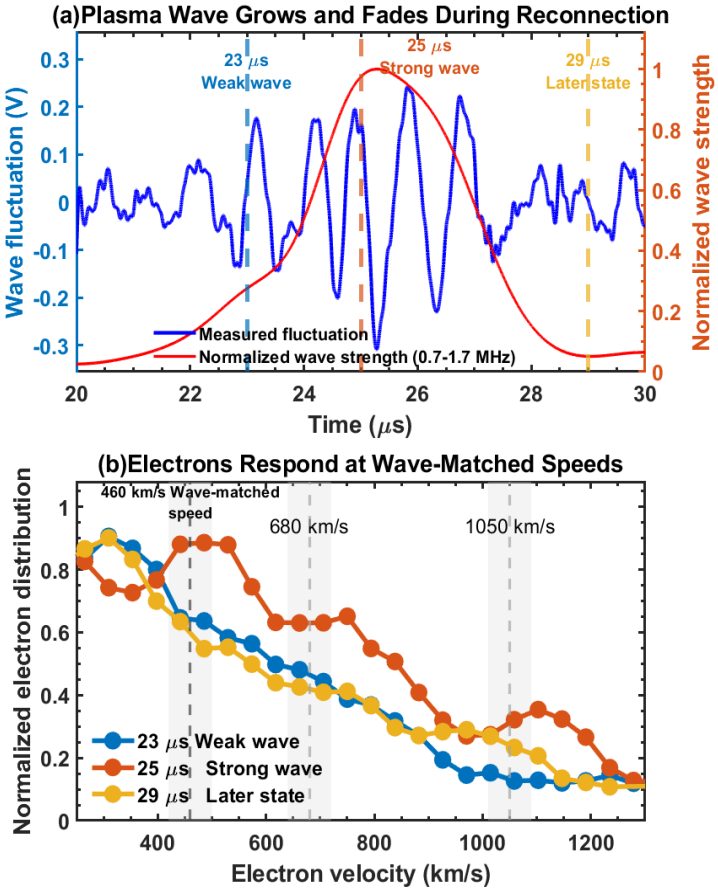


Figure 2: (a) Plasma waves and (b) electrons during magnetic reconnection. As the waves grow and fade, electrons at wave-matched speeds show corresponding changes in their velocity distribution.

Figure 2 illustrates this connection. The upper panel shows the plasma wave growing and then fading during magnetic reconnection. The lower panel shows the electron velocity distribution at three stages of that evolution. When the wave is strongest, the electron distribution develops pronounced features near velocities that match that of the plasma waves. Later, after the wave has weakened, those features also change.

Spacecraft provide invaluable measurements of magnetic reconnection in space, but are limited to sampling a small number of points as they pass through a complex, three-dimensional system. In the laboratory, researchers can instead create the same plasma conditions repeatedly, building up measurements at many locations and times and reconstructing how the plasma evolves in three dimensions.

This study takes advantage of PHASMA's unusually extensive suite of high-resolution optical diagnostics, which provides a detailed view of the electron distribution function. These measurements allow researchers to probe not just the bulk properties of the plasma, but how individual populations of particles move and gain energy during magnetic reconnection. By revealing these microscopic processes in a controlled, three-

dimensional experiment, the research provides an important step toward understanding—and better predicting—the bursts of solar energy that can damage satellites and disrupt communications and power systems.

The research was carried out at West Virginia University's PHASMA facility and has been accepted for publication in *Physical Review Letters, DOI: https://doi.org/10.1103/w5l7-jc9r* .

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Abstract

KTI01/5 Direct Measurements of Electron Energization During Magnetic Reconnection

Session KTI01: Fundamental Plasmas
2:00 PM–5:00 PM, Wednesday, November 4, 2026
Room: Hilton Chicago, International North, Second Floor