

To Understand the ‘Forest,’ You Need to See the Subatomic Particles

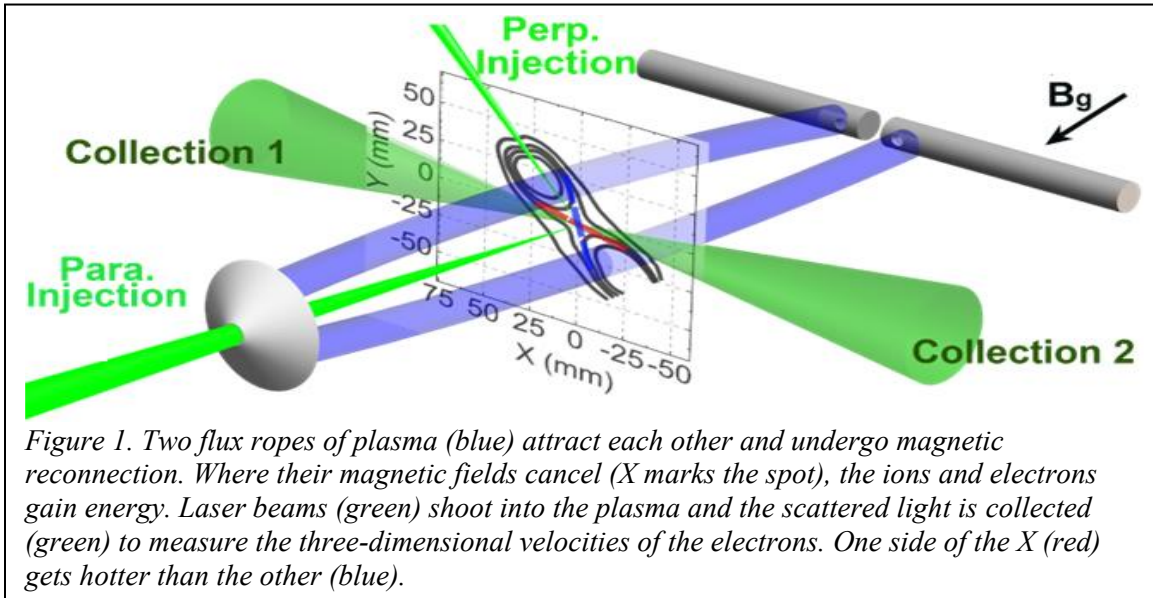
Directly measuring the velocity and position of electrons and ions in a plasma has provided new insight into how they gain energy.

LONG BEACH, Calif. — From solar flares, to the northern lights, to the cores of fusion reactors, a single physical process connects them all: magnetic reconnection. This fundamental phenomenon converts energy from magnetic fields to the collection of hot, charged particles that make up a plasma. In the solar corona, the resultant explosions can be enormous – magnetic reconnection can send chunks of plasma the size of Mount Everest hurtling through the solar system. However, understanding how magnetic reconnection works, and someday predicting when these explosions will occur, requires disentangling the physics occurring on the scale of individual ions and electrons.

The ions and electrons that make up plasma are far too small to see with the naked eye; even the most powerful microscope on Earth is not strong enough to see individual electrons and ions. But if we could see these individual “trees,” we could more completely understand the “forest” that is a swirling mass of plasma. Now researchers at West Virginia University have built an experiment, the PHase Space Mapping (PHASMA) experiment, specifically designed to measure the location and three-dimensional motion of ions and electrons in a plasma at the smallest scales.

The novel advance of the PHASMA experiment is to use lasers, like police use radar guns, to measure the position and speed of ions and electrons in a plasma. It is the location and motion of these charged particles that define the properties of a plasma: its density, its flow speed, and its temperature. The ions and electrons in plasmas also have the unique property of responding collectively to applied magnetic and electric fields – like a school of fish might respond to seeing a shark swimming towards them. However, instead of running directly away from the shark, when a magnetic field threads through a plasma the ions and electrons move in helical paths around the direction of the magnetic field. Plasmas are different than solids, liquids, and gases because in plasma temperature is often different along and perpendicular to the magnetic field.

To understand how the magnetic field transfers its energy to the particles in magnetic reconnection, it’s important to know the exact details of the temperature right at the spot where the reconnection is occurring (Figure 1). Previously existing laboratory diagnostics did not have the capability to measure the particle velocities in all three directions.



This new diagnostic approach has led to surprising discoveries about how magnetic reconnection heats the plasma. When the entire plasma is smaller than the radius of the helical path of the ions, physicists had assumed that the ions would not be affected by magnetic reconnection. New PHASMA experiments show that the ions get very hot during such reconnection – much hotter than the electrons. This experimental result cannot be explained by existing theory, but that is the result of the best sort of experiment – more questions than answers.

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Abstract

[SR02.1](#)

Session

[Exploration of kinetic plasma physics through in-situ phase-space measurements in laboratory plasmas](#)

[SR02: Invited Session Review: Exploration of kinetic plasma physics through in-situ phase-space measurements in laboratory plasmas](#)

8:00 AM–9:00 AM, Thursday, November 20, 2025

Room: Grand Ballroom I