Tracking major sources of energy loss in compact fusion facilities

June 11 2019, by John Greenwald

Physicist Walter Guttenfelder. Credit: Elle Starkman/PPPL Office of Communications

A key obstacle to controlling on Earth the fusion that powers the sun and stars is leakage of energy and particles from plasma, the hot, charged state of matter composed of free electrons and atomic nuclei that fuels fusion reactions. At the U.S. Department of Energy's (DOE) Princeton Plasma Physics Laboratory (PPPL), physicists have been focusing on validating computer simulations that forecast energy losses caused by turbulent transport during fusion experiments.

Researchers used codes developed at General Atomics (GA) in San Diego to compare theoretical predictions of electron and ion turbulent transport with findings of the first campaign of the laboratory's compact—or "low-aspect ratio"—National Spherical Torus Experiment-Upgrade (NSTX-U). GA, which operates the DIII-D National Fusion Facility for the DOE, has developed codes well-suited for this purpose.

Low-aspect ratio tokamaks are shaped like cored apples, unlike the more widely used conventional tokamaks that are shaped like doughnuts.

State-of-the-art codes

"We have state-of-the-art codes based on sophisticated theory to predict transport," said physicist Walter Guttenfelder, lead author of a *Nuclear Fusion* paper that reports the findings of a team of researchers. "We must now validate these codes over a broad range of conditions to be confident that we can use the predictions to optimize present and future experiments."

Analysis of the transport observed in NSTX-U experiments found that a major factor behind the losses was turbulence that caused the transport of electrons to be "anomalous," meaning that they spread rapidly, similar to the way that milk mixes with coffee when stirred by a spoon. The GA codes predict the cause of these losses to be a complex mix of three different types of turbulence.

The observed findings opened a new chapter in the development of predictions of transport in low-aspect ratio tokamaks—a type of fusion facility that could serve as a model for next-generation fusion reactors that combine light elements in the form of plasma to produce energy. Scientists around the world are seeking to replicate fusion on Earth for a virtually inexhaustible supply of power to generate electricity.

Researchers at PPPL now aim to identify the mechanisms behind the anomalous electron transport in a compact tokamak. Simulations predict that such energy loss stems from the presence of three distinct types of complex turbulence—two types with relatively long wavelengths and a third with wavelengths a fraction of the size of the larger two.

The impact of one of the two long-wave types, which is typically found in the core of low-aspect ratio tokamaks as well as in the edge of the plasma in conventional tokamaks, must be fully taken into account when predicting low-aspect ratio transport.

Challenge to simulate

However, the combined impact of all three types of turbulence is a challenge to simulate since scientists normally study the different wavelengths separately. Physicists at the Massachusetts Institute of Technology (MIT) have recently performed multi-scale simulations and their work highlights the significant supercomputer time such simulations require.

Researchers must now test additional simulations to achieve more complete agreement between predictions of transport and experiments on plasmas in low-aspect ratio tokamaks. Included in these comparisons will be measurements of turbulence taken by University of Wisconsin-Madison coauthors of the *Nuclear Fusion* paper that will better constrain predictions. Improved agreement will provide assurance of energy-loss predictions for present and future facilities.

More information: W. Guttenfelder et al, Initial transport and turbulence analysis and gyrokinetic simulation validation in NSTX-U L-mode plasmas, *Nuclear Fusion* (2019). [DOI: 10.1088/1741-4326/ab0b2c](https://doi.org/10.1088/1741-4326/ab0b2c)

Provided by Princeton Plasma Physics Laboratory