Researchers advance understanding of turbulence that drains heat from fusion reactors

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PPPL Physicists Walter Guttenfelder and Yang Ren stand in the NSTX control room. Credit: Elle Starkman / PPPL's Office of Communication

The life of a subatomic particle can be hectic. The charged nuclei and electrons that zip around the vacuum vessels of doughnut-shaped fusion machines known as tokamaks are always in motion. But while that motion helps produce the fusion reactions that could power a new class of electricity generator, the turbulence it generates can also limit those reactions.

Now, physicists at the U.S. Department of Energy's Princeton Plasma Physics Laboratory (PPPL) appear to have gained important new insights into what affects this turbulence, which can impact the leakage of heat from the fusion plasma within tokamaks. Understanding how fusion plasmas lose heat is crucial because the more a plasma is able to retain its heat the more efficient a fusion reactor can be. Such understanding could improve the performance of ITER, the multinational tokamak being built in France, by leading to a reduction in heat leakage.

Results of this research have been published in a series of papers, with the most recent one in *Physics of Plasmas* in December 2015. Initial observations were reported in *Physical Review Letters* in 2011 and in *Physics of Plasmas* in 2012. The research was supported by the DOE's Office of Science.

The findings build on the fact that the center of the plasma gets much hotter than the edge during the operation of a tokamak. Turbulence then tends to drive the ions and electrons in the hot central plasma towards the edge, just as the hotter water at the bottom of a tea kettle tends to mix with the cooler water at the top, keeping the water, or plasma, from getting as hot as it otherwise could. But when scientists create what's known as a "high density gradient," by making the density of the plasma change rapidly from high at the center to low at the edges, the plasma can get hotter before that heat starts to leak.

At PPPL, a team of researchers including physicists Yang Ren and Walter Guttenfelder has now shown that a steep density gradient can also reduce the strength of the electron turbulence. To continue the tea kettle analogy, a steep density gradient can weaken the intensity of the boiling. And weaker boiling, or turbulence, means that less heat escapes from the plasma.

The physicists did their research on PPPL's National Spherical Torus Experiment (NSTX), a spherical tokamak that is shaped like a cored apple, prior to its recent upgrade. "NSTX is one of the few tokamaks in the world that can obtain a direct measurement of electron-scale turbulence," said Juan Ruiz Ruiz, a graduate student at MIT and first author of the most recent paper.

Using PPPL computers, the team analyzed the data produced during 2010 NSTX experiments when scientists used a diagnostic called a high-k scattering device that beams microwaves into the plasma and measures how they scatter. The data confirmed that the turbulence was low when the density gradient was steep.

To analyze how the density gradient affected the strength of the electron turbulence, the team fed information about the plasma's temperature and density into a program run on computers at the National Energy Research Scientific Computing Center, a DOE Office of Science User Facility at Lawrence Berkeley National Laboratory in Berkeley, California. The results showed that the steep gradient reduced the strength of the electron turbulence much more than earlier theories had predicted.

The paper's discussion of electron turbulence complements MIT research that was recently reported in the journal Nuclear Fusion. Simulations of experiments on MIT's Alcator C-Mod, a conventional tokamak that is shaped like a doughnut, found that electron-scale turbulence can contribute significantly to the much larger ion-scale turbulence that is thought to dominate heat loss in conventional tokamaks.

This contribution was demonstrated in multiscale simulations, led by MIT research scientist Nathan Howard, that contradicted a common assumption that the impact of electrons was virtually negligible in conventional tokamaks. The separate Ruiz research provided further evidence of the importance of electrons to the turbulent transport of plasma. The spherical tokamak this research was based on enables the impact of electrons to be more readily seen, since the much larger ion-scale turbulence in such tokamaks is usually suppressed.

"Understanding the stabilizing mechanisms of the turbulence is definitely an important task in order to gain a predictive capability in the design of future fusion reactors," said Ruiz. "Further investigation is required to understand heat losses in tokamaks, and the upgraded version of the NSTX, the NSTX-U, will certainly be used to investigate this issue in detail."

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