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Building a star in a smaller jar

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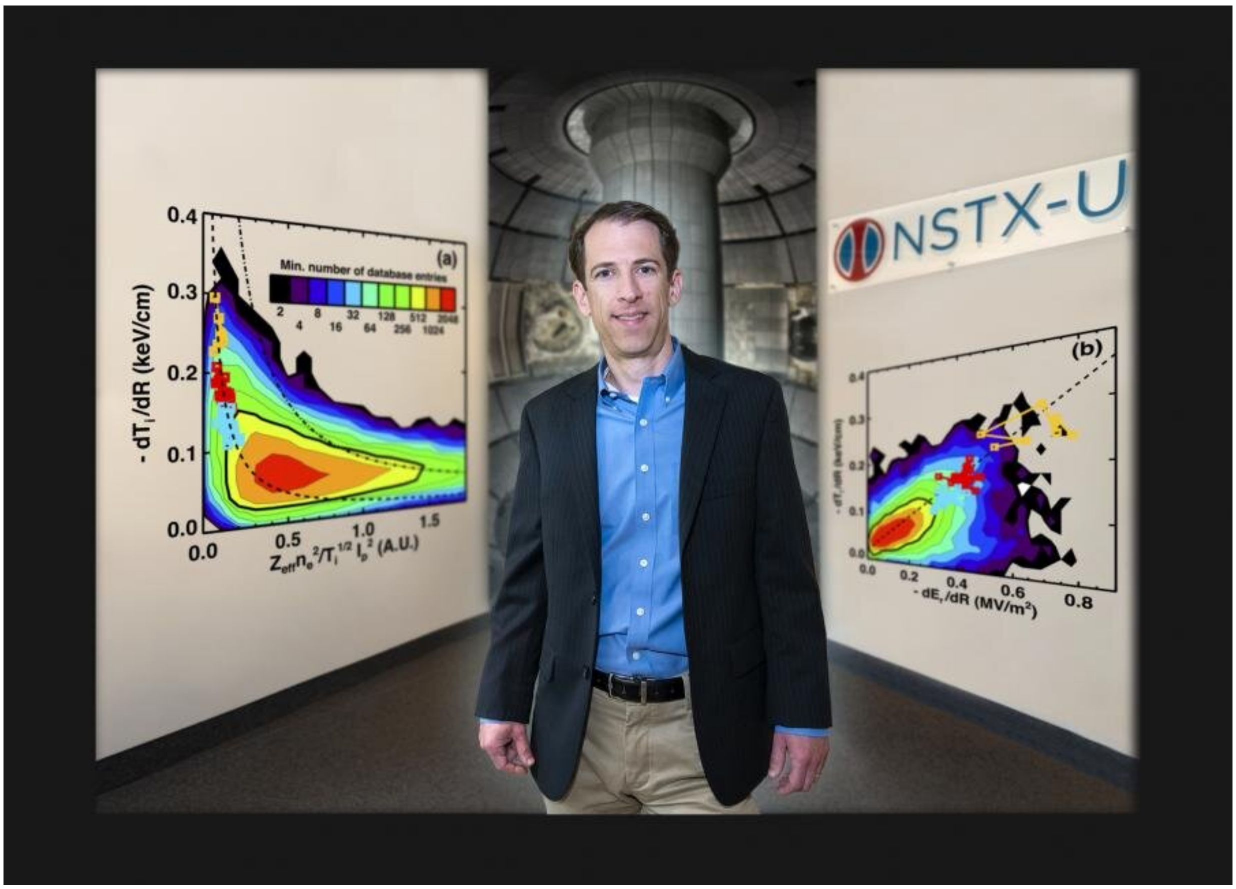

PPPL physicist Devon Battaglia with graphs illustrating fusion plasma in enhanced pedestal H-mode. Credit: Elle Starkman

Researchers at the U.S. Department of Energy's (DOE) Princeton Plasma Physics Laboratory (PPPL) have gained a better understanding of a promising method for improving the confinement of superhot fusion plasma using magnetic fields. Improved plasma confinement could enable a fusion reactor called a spherical tokamak to be built smaller and less expensively, moving the world closer to reproducing on Earth the fusion energy that powers the sun and stars.

The improved confinement is made possible by the so-called enhanced pedestal (EP) H-mode, a variety of the high performance, or H-mode, plasma state that has been observed for decades in tokamaks around the world. When a fusion plasma enters H-mode, it requires less heating to get to the superhot temperatures necessary for fusion reactions.

The new understanding reveals some of the underlying mechanics of EP H-mode, a condition that researchers discovered more than a decade ago. Scientists led by physicists at PPPL have now found that the EP H-mode improves upon H-mode in spherical tokamaks by lowering the density of the plasma edge.

The reduced density occurs in EP H-mode when small instabilities in the plasma edge eject relatively cold, low-energy particles. With fewer cold particles to bump into, the hotter particles in the plasma are less likely to leak out.

"As the higher energy particles stay in the plasma in larger quantities, they increase the pressure in the plasma, feeding the instabilities that throw out colder particles and further lowering the edge density," said PPPL physicist Devon Battaglia, lead author of a paper reporting the results in *Physics of Plasmas*. "Ultimately, the fortuitous interaction allows the plasma to stay hotter with the same heating and little change to the average plasma density."

Physicists want to understand the conditions under which EP H-mode occurs so they can recreate them in future fusion power plants. "If we could run the plasma with this characteristic in a steady-state fashion, it would provide an additional route to optimize the size and power gain of future fusion reactors," said PPPL physicist Walter Guttenfelder, one of the researchers who contributed to the findings.

Fusion reactors combine light elements in the form of plasma—the hot, charged state of matter composed of free electrons and atomic nuclei—to generate large amounts of energy. Scientists use fusion reactors to develop the process that drives the sun and stars for a virtually inexhaustible supply of power to generate electricity.

Physicists Rajesh Maingi and David Gates discovered EP H-mode in 2009 while using PPPL's National Spherical Torus Experiment (NSTX), the predecessor of the National Spherical Torus Experiment-Upgrade (NSTX-U). "Their discovery was exciting because the confined plasma reorganized and did a better job of holding on to its heat without a big change in the amount of plasma," said Battaglia.

"It's like adding better insulation to your house," he said. "The more the plasma holds on to its heat, the smaller you can make the device, since you don't need additional layers of plasma to insulate the hot core." Moreover, he added, "by taking a leap in our understanding of how EP H-mode comes about, we can have more confidence in being able to predict if it's going to happen. The next step is to use the new capabilities of NSTX-U to demonstrate that we can take advantage of this process in our designs for fusion reactors."

More information: D. J. Battaglia et al. Enhanced pedestal H-mode at low edge ion collisionality on NSTX, *Physics of Plasmas* (2020). DOI: 10.1063/5.0011614

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