Toward fusion energy, team models plasma turbulence on the nation's fastest supercomputer

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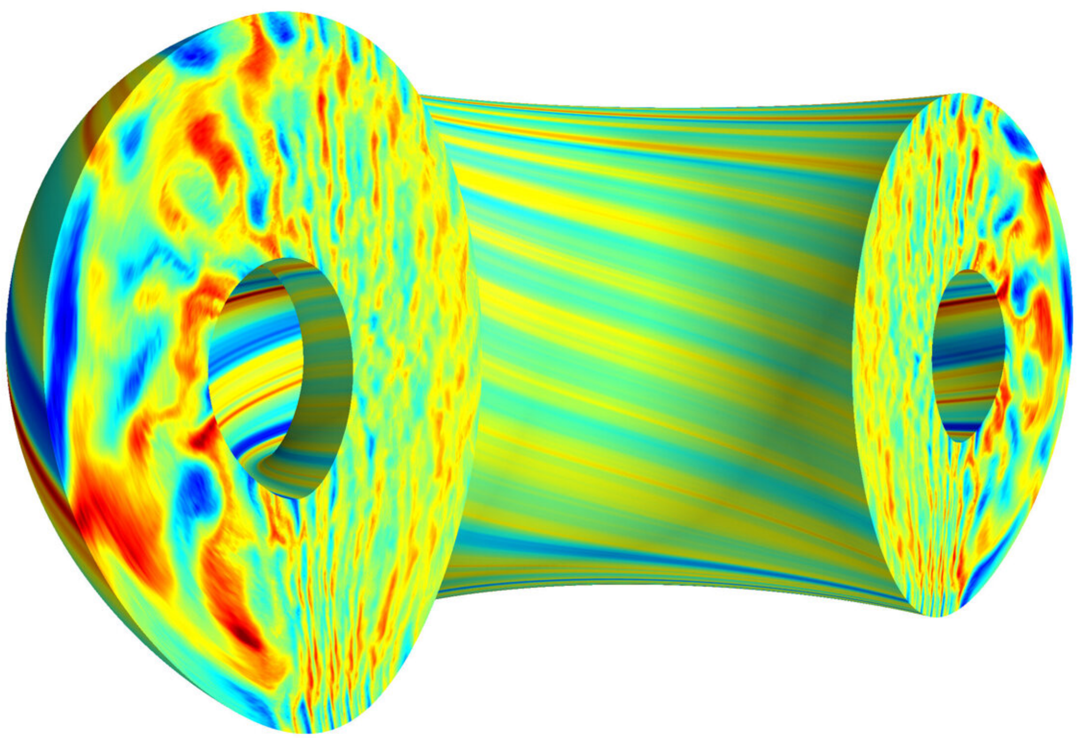

A visualization of deuterium-tritium density fluctuations in a tokamak driven by turbulence. Areas of red are representative of high density and areas of blue are representative of low density. Credit: Emily Belli, General Atomics

A team modeled plasma turbulence on the nation's fastest supercomputer to better understand plasma behavior

The same process that fuels stars could one day be used to generate massive amounts of power here on Earth. Nuclear fusion—in which atomic nuclei fuse to form heavier nuclei and release energy in the process—promises to be a long-term, sustainable, and safe form of energy. But scientists are still trying to fine-tune the process of creating net fusion power.

A team led by computational physicist Emily Belli of General Atomics has used the 200-petaflop Summit supercomputer at the Oak Ridge Leadership Computing Facility (OLCF), a US Department of Energy (DOE) Office of Science user facility at Oak Ridge National Laboratory (ORNL), to simulate energy loss in fusion plasmas. The team used Summit to model plasma turbulence, the unsteady movement of plasma, in a nuclear fusion device called a tokamak. The team's simulations will help inform the design of next-generation tokamaks like ITER with optimum confinement properties. ITER is the world's largest tokamak, which is being built in the south of France.

"Turbulence is the main mechanism by which particle losses happen in the plasma," Belli said. "If you want to generate a plasma with really good confinement properties and with good fusion power, you have to minimize the turbulence. Turbulence is what moves the particles and energy out of the hot core where the fusion happens."

The simulation results, which were published in *Physics of Plasmas* earlier this year, provided estimates for the particle and heat losses to be expected in future tokamaks and reactors. The results will help scientists and engineers understand how to achieve the best operating scenarios in real-life tokamaks.

A balancing act

In the fusion that occurs in stars like our sun, two hydrogen ions (i.e., positively charged proton particles) fuse to form helium ions. However, in experiments on Earth, scientists must use hydrogen isotopes to create fusion. Each hydrogen isotope has one positively charged proton particle, but different isotopes carry different numbers of neutrons. These neutral particles don't have a charge, but they do add mass to the atom.

Traditionally, physicists have used pure deuterium—a hydrogen isotope with one neutron—to generate fusion. Deuterium is readily available and easier to handle than tritium, a hydrogen isotope with two neutrons. However, physicists have known for decades that using a mixture of 50 percent deuterium and 50 percent tritium yields the highest fusion output at the lowest temperature.

"Even though they've known this mixture gives the greatest amount of fusion output, almost all experiments for the last few decades have only used pure deuterium," Belli said. "Experiments using this mixture have only been done a few times over the past few decades. The last time it was done was more than 20 years ago."

To ensure the plasma is confined in a reactor and that energy is not lost, both the deuterium and tritium in the mixture must have equal particle fluxes, an indicator of density. Scientists aim to maintain a 50-50 density throughout the tokamak core.

"You want the deuterium and the tritium to stay in the hot core to maximize the fusion power," Belli said.

Supercomputing powers fusion simulations

To study the phenomenon, the team competed for and won computing allocations on Summit through two allocation programs at the OLCF. These were the Advanced Scientific Computing Research Leadership Computing Challenge, or ALCC, and the Innovative and Novel Computational Impact on Theory and Experiment, or INCITE, programs.

The researchers modeled plasma turbulence on Summit using the CGYRO code codeveloped by Jeff Candy, director of theory and computational sciences at General Atomics and co-principal investigator on the project. CGYRO was developed in 2015 from the GYRO legacy computational plasma physics code. The developers designed CGYRO to be compatible with the OLCF's Summit system, which debuted in 2018.

"We realized in 2015 that we wanted to upgrade our models to handle these self-sustaining plasma regimes better and to handle the multiple scales that arise when you have different types of ions and electrons, like in these deuterium-tritium plasmas," Belli said. "It became clear that if we wanted to update our models and have them be highly optimized for next-generation architectures, then we should start from the ground up and completely rewrite the code. So that's what we did."

With Summit, the team could include both isotopes—deuterium and tritium—in their simulations.

"Up until now, almost all simulations have only included one of these isotopes—either deuterium or tritium," Belli said. "The power of Summit enabled us to include both as two separate species, model the full dimensions of the problem, and resolve it at different time and spatial scales."

Results for the real world

Experiments using deuterium-tritium fuel mixtures are now being carried out for the first time since 1997 at the Joint European Torus (JET), a fusion research facility at the Culham Centre for Fusion Energy in Oxfordshire, UK. The experiments at the JET facility will help scientists and engineers develop fuel control practices for maintaining a 50-50 ratio of deuterium to tritium. Belli said it will likely be the last time deuterium-tritium experiments are run until ITER, the world's largest tokamak, is built.

"The experimental team is getting results as we speak, and in the next few months, the data will be analyzed," Belli said.

The results will give scientists a better idea of the behavior of deuterium-tritium fuel for a practical fusion reactor.

"This fuel gives you the highest fusion output at the lowest temperature, so you don't have to heat it quite as hot to get an enormous amount of fusion power out of it," Belli said.

"Because it's been so long since these kinds of experiments have been done, our simulations are important to predict the behavior of this fuel mixture to plan for ITER. Summit is giving us the power to do just that."

More information: E. A. Belli et al, Asymmetry between deuterium and tritium turbulent particle flows, *Physics of Plasmas* (2021). DOI: 10.1063/5.0048620

Provided by Oak Ridge National Laboratory

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