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New Model Sheds Light on Key Physics of Magnetic Islands that Can Halt Fusion Reactions

A large-scale simulation reveals a surprising observation: A magnetic island does not necessarily dangerously perturb the plasma current and thereby degrade or destroy fusion performance.

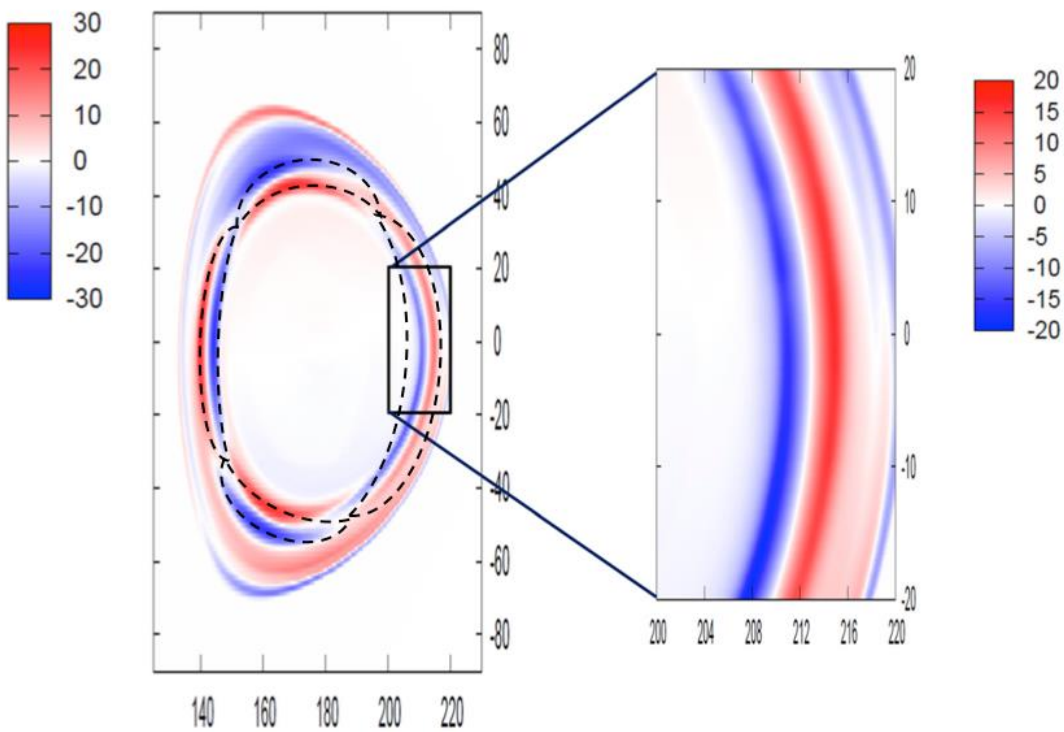

Image caption: Contour plot of a cross-section plane around the magnetic island, showing the variation of the electrostatic potential associated with the magnetic island. The sharp negative (blue) and positive (red) variation indicates a strongly sheared $\boldsymbol{E} \times \boldsymbol{B}$ flow driven by electric and magnetic fields that can mitigate the impact of the islands.

The Science

Fusion, the power that drives the sun and stars, is the fusing of light atomic elements in the form of plasma — the hot, charged state of matter composed of free electrons and atomic nuclei — that generates massive amounts of energy. Scientists are seeking to replicate fusion on Earth for a virtually inexhaustible supply of power to generate electricity.

Problematically, “magnetic islands”, bubble-like structures that form in fusion plasmas, can grow and thereby degrade and potentially disrupt the plasma confinement and damage the doughnut-shaped tokamak facilities that house fusion reactions. Think of a Formula One racing car with a leaky tire: the tire will go flat, and the car will slow down and maybe crash. That’s how scientists used to think about the impact of magnetic islands. Previous theoretical models *assumed* that the magnetic islands would degrade the confinement and perturb the plasma current, and that this in turn would cause the islands to grow even larger, leading to a crash. A deeper understanding of how islands interact with the complicated particle motions, the plasma flow, turbulence etc. was missing because of the lack of detailed calculations.

Previous investigators didn't have the proper numerical codes needed to perform the required studies, or enough computer resources to run them. This is where the DOE-funded XGC kinetic particle simulation code comes in. Recent research using XGC has overturned long-held assumptions to produce a new model that could be crucial for understanding how magnetic islands interact with the surrounding plasma.

The Impact

With tour de force computer simulations, XGC tracks the motion of trillions of electrically charged and neutral particles in turbulent electric and magnetic fields. The simulations include collisions between the particles and heating and radiative losses in the plasma. When an international team led by scientists from the Princeton Plasma Physics Laboratory (PPPL) used XGC to model plasma conditions in the KSTAR experiment in Korea, the structure of the islands proved markedly different from standard assumptions; as did the impact of the islands on plasma flow, turbulence, plasma confinement, and perhaps most importantly, on the plasma currents. Moreover, against all previous theoretical assumptions, the plasma confinement around the magnetic island did not degrade and the perturbed plasma current did not lead to accelerated island growth. So, unlike Formula One cars with leaky tires, tokamaks with imperfections such as magnetic islands can still perform as intended. This is good news for future fusion reactors!

The massive supercomputer simulations used 6.2 million processor-core hours on the Cori supercomputer at the National Energy Research Scientific Computing Center (NERSC), a DOE Office of Science User Facility at Lawrence Berkeley National Laboratory (LBNL). The calculation showed that the plasma turbulence can penetrate into the islands, that pressure gradients can be maintained, and that the plasma flow across them can be strongly sheared. This shearing mitigates the impact of the islands so that plasma confinement can be maintained while the islands grow, as was observed in KSTAR.

Summary

These findings could lay new groundwork for understanding the precursor physics that can lead to plasma disruptions, one of the most dangerous events a tokamak reactor can encounter. Disruptions need to be controlled before they grow. Looking forward, the larger-scale computers of the future will allow researchers to use the XGC code to simulate the spontaneous formation of the magnetic islands and to understand when they will and will not grow under self-consistent interaction with the sheared plasma flow and plasma turbulence. This will help researchers better understand when the islands are benign, and when conditions can cause the islands to deteriorate plasma performance.

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Publications

Jae-Min. Kwon, S. Ku, M. J. Choi, C. S. Chang, R. Hager, E. S. Yoon, H. H. Lee, and H. S. Kim, "Gyrokinetic simulation study of magnetic island effects on neoclassical physics and micro-instabilities in a realistic KSTAR plasma," *Physics of Plasmas* **25**, 052506 (2018). [DOI: 10.1063/1.5027622]

Highlight Categories

Program: ASCR, FES

Performer/Facility: DOE Laboratory, Industry, SC User Facilities, ASCR User Facilities, NERSC