New model sheds light on key physics of magnetic islands that halt fusion reactions

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Magnetic islands, bubble-like structures that form in fusion plasmas, can grow and disrupt the plasmas and damage the doughnut-shaped tokamak facilities that house fusion reactions. Recent research at the U.S. Department of Energy's (DOE) Princeton Plasma Physics Laboratory (PPPL) has used large-scale computer simulations to produce a new model that could be key to understanding how the islands interact with the surrounding plasma as they grow and lead to disruptions.

The findings, which overturn long-held assumptions of the structure and impact of magnetic islands, are from simulations led by visiting physicist Jae-Min Kwon. Kwon, on a year-long sabbatical from the Korean Superconducting Tokamak Advanced Research (KSTAR) facility, worked with physicists at PPPL to model the detailed and surprising experimental observations recently made on KSTAR.

Researchers intrigued

"The experiments intrigued many KSTAR researchers including me," said Kwon, first author of the new theoretical paper selected as an Editor's Pick in the journal *Physics of Plasmas*. "I wanted to understand the physics behind the sustained plasma confinement that we observed," he said. "Previous theoretical models assumed that the magnetic islands simply degraded the confinement instead of sustaining it. However, at KSTAR, we didn't have the proper numerical codes needed to perform such studies, or enough computer resources to run them."

The situation turned Kwon's thoughts to PPPL, where he has interacted over the years with physicists who work on the powerful XGC numerical code that the Laboratory developed. "Since I knew that the code had the capabilities that I needed to study the problem, I decided to spend my sabbatical at PPPL," he said.

Kwon arrived in 2017 and worked closely with C.S. Chang, a principal research physicist at PPPL and leader of the XGC team, and PPPL physicists Seung-Ho Ku, and Robert Hager. The researchers modeled magnetic islands using plasma conditions from the KSTAR experiments. The structure of the islands proved markedly different from standard assumptions, as did their impact on plasma flow, turbulence, and plasma confinement during fusion experiments.

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.

Long-absent understanding

"Understanding how islands interact with plasma flow and turbulence has been absent until now," Chang said. "Because of the lack of detailed calculations on the interaction of islands with complicated particle motions and plasma turbulence, the estimate of the confinement of plasma around the islands and their growth has been based on simple models and not well understood."

The simulations found the plasma profile inside the islands not to be constant, as previously thought, and to have a radial structure. The findings showed that turbulence can penetrate into islands and that the plasma flow across them can be strongly sheared so that it moves in opposite directions. As a result, plasma confinement can be maintained while the islands grow.

These surprising findings contradicted past models and agreed with the experimental observations made on KSTAR. "The study exhibits the power of supercomputing on problems that could not be studied otherwise," Chang said. "These findings could lay new groundwork for understanding the physics of plasma disruption, which is one of the most dangerous events a tokamak reactor could encounter."

Millions of processor hours

Computing the new model required 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. The processing time equaled thousands of years on a desktop computer. "What I wanted was quantitatively accurate results that could be directly compared with the KSTAR data," Kwon said. "Fortunately, I could access enough resources on NERSC to achieve that goal through the allocation given to the XGC program. I am grateful for this opportunity."

Going forward, a larger scale computer could allow the XGC code to start from the spontaneous formation of the magnetic islands and show how they grow, in self-consistent interaction, with the sheared plasma flow and plasma turbulence. The results could lead to a way to prevent disastrous disruptions in fusion reactors.

More information: Jae-Min Kwon et al, Gyrokinetic simulation study of magnetic island effects on neoclassical physics and micro-instabilities in a realistic KSTAR plasma, *Physics of Plasmas* (2018). DOI: 10.1063/1.5027622

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