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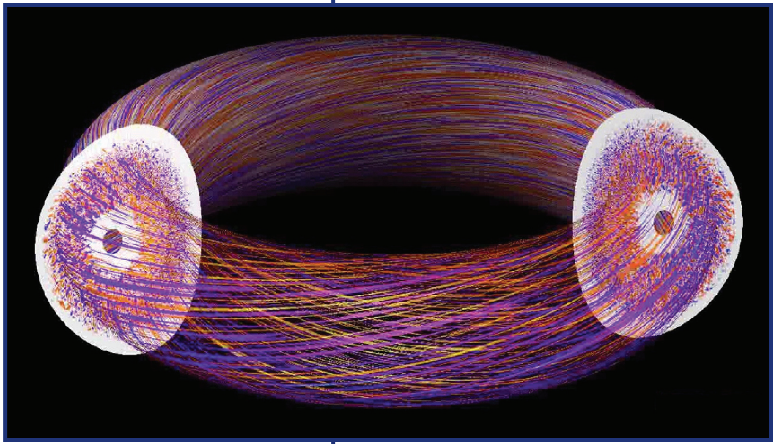
3-D Simulations of Tokamak Plasmas Conducted at ORNL

Fusion energy research is still in the preliminary stages of theory and simulation, but its potential as a source of clean, virtually unlimited power is slowly being realized at Oak Ridge National Laboratory's (ORNL's) National Center for Computational Sciences (NCCS).



Small eddies created by plasma turbulence are shown in cross-section along with the magnetic field lines threading the simulated tokamak. Image produced by W. X. Wang, PPPL,and S. Klasky, ORNL

The Gyrokinetic Plasma Simulation team headed by W. W. Lee of the Princeton Plasma Physics Laboratory is using NCCS supercomputers to work toward tapping that potential by exploring turbulence transport, or heat and particle loss, in tokamak reactors.

Tokamaks are doughnut-shaped devices that house the ionized gas responsible for sparking the fusion reaction necessary to produce energy. According to Lee, whose team is simulating turbulent transport on NCCS's Jaguar system, plasmas confined in tokamaks have natural temperature and density gradients that greatly affect the transfer of heat and particles throughout the device. In the core the temperature is hotter and the density higher, while near the walls the temperature gradually becomes cooler and the density lower. These gradients, says Lee, create turbulence, causing significant heat and particle loss in the tokamak.

If the turbulence is too great and the device loses too much heat, the core cannot reach the temperature necessary to ignite a sufficient reaction, sending the entire fusion process into an early demise. Lee's team hopes to create a more consistent environment for ignition reactions by minimizing the effect of the gradients on turbulence and thereby maintaining temperatures in the tokamak.

Lee's project studies two "scaling laws" related to tokamak reactors. The first explores the physical size necessary for a tokamak to achieve ignition. Just as the core must be heated to reach a proper temperature, it likewise must be large enough to facilitate the necessary reactions. Size scaling also helps the researchers determine how confinement can be improved with the application of magnetic fields. According to Lee, a stronger field leads to better confinement, but the relationship is not perfectly understood.

The second investigation involves isotopes and aims to clarify the contradictory theoretical and experimental results surrounding the combination of hydrogen, deuterium, and tritium.

Traditionally, most fusion experiments have used deuterium and hydrogen; but both Lee's simulations and ITER (an upcoming experimental reactor in France that aims to determine the feasibility of fusion power production), as well as several large tokamaks around the world, introduce tritium into the equation.

"Experimental results and theoretical understanding [regarding tritium] don't agree," Lee says, adding that while some theories suggest that tritium will weaken confinement and aggravate heat loss, experiments suggest just the opposite. For ITER, and for "real fusion," as Lee calls it, it is crucial to introduce tritium to achieve a proper reaction. While tritium is radioactive and requires special handling, its half-life of roughly 10 years is much more manageable than that of traditional nuclear waste from fission reactors, which can be upward of 10,000 years.

Lee cites his code's ability to scale with the Jaguar system as one of its major advantages, adding that it is also capable of scaling well with different machines. Eventually, says Lee, his team hopes to gain access to the planned petascale facilities at the NCCS, which will allow the team to simulate a fusion reactor the size of the proposed ITER facility. The project used 3.5 million processor hours last year, producing successful three-dimensional simulations. In 2007, the project has been awarded 6 million processor hours on the Jaguar system and another 45,000 hours on the Phoenix system through the Department of Energy program Innovative and Novel Computational Impact on Theory and Experiment (INCITE). Lee calls the computing power available at the NCCS "crucial" to his team's research and emphasizes the importance of continuing the fruitful interactions with members of ORNL's Scientific Computing Group.

"Dr. Scott Klasky of NCCS is a co-principal investigator of our SciDAC [Scientific Discovery through Advanced Computing] project, and he serves as a crucial link for us in accessing these resources," says Lee. "We want them to provide us with the fastest and most powerful computers available and the most advanced software tools. We are on our way."

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