Impact of Particle Motion on Three Dimensional Tokamak Equilibrium

Research shows the interaction between micro particle motion and macro plasma behavior is crucial to predict 3D equilibrium in advanced operation of high pressure tokamak fusion devices.

Fusion reactions, the source of the sun's power, fuse two light atomic nuclei and releases energy. The process happens at extremely high temperatures, where the fusion fuel is ionized forming one of the four fundamental states of matter – plasma. To bring this stellar power source to Earth and control the fusion process, scientists confine the hot plasma gas with strong magnetic fields.

The tokamak, the leading concept in magnetically confined fusion devices, has the shape of a donut. Their intrinsic axisymmetry like a donut can better sustain nested magnetic surfaces and hot charged particles within the surfaces than any other concepts. Interestingly, a small amount of externally applied, non-axisymmetric magnetic field can modify tokamak plasmas and break the axisymmetry. This can lead to three-dimensional (3D) tokamak equilibrium states. The properly controlled 3D equilibrium can be very beneficial to improve the performance of tokamak devices.

Therefore, the accurate prediction of the experimental 3D equilibrium becomes essential in plasma physics. Scientists at Princeton Plasma Physics Laboratory, Culham Centre for Fusion Energy and General Atomics are combining the micro particle motion, described by kinetic theory, and the macro fluid behavior of plasma into a new hybrid kinetic-magnetohydrodynamic (MHD) model. The hybrid kinetic-MHD simulation, performed by the advanced MARS-K code, resolves the long-standing issue of large disagreement between the 3D equilibrium, predicted by fluid MHD theory alone, and the experimental observations in high pressure tokamak plasmas. Through the sophisticated comparison, the hybrid kinetic-MHD simulation shows a very good quantitative agreement with various 3D equilibrium experiments. Figure 1 shows the structure of 3D equilibrium is strongly modified by the interaction between the particle motion and global fluid behavior in DIII-D experiments. The detailed results and model validations are published in the paper "Three-Dimensional Drift Kinetic Response of High-β Plasmas in the DIII-D Tokamak", Physics Review Letter **114**, 145005 (2015).

This work, for the first time, fills the gap between theory and experiments in 3D equilibrium studies. The experimentally validated model also provides a powerful tool that enables scientists to better understand the underlying physics of experimental observations. The ability to reliably predict the plasma behavior will help scientists to better control tokamaks and achieve higher performance in currently operating machines as well as in the next step fusion energy devices, such as ITER and DEMO.

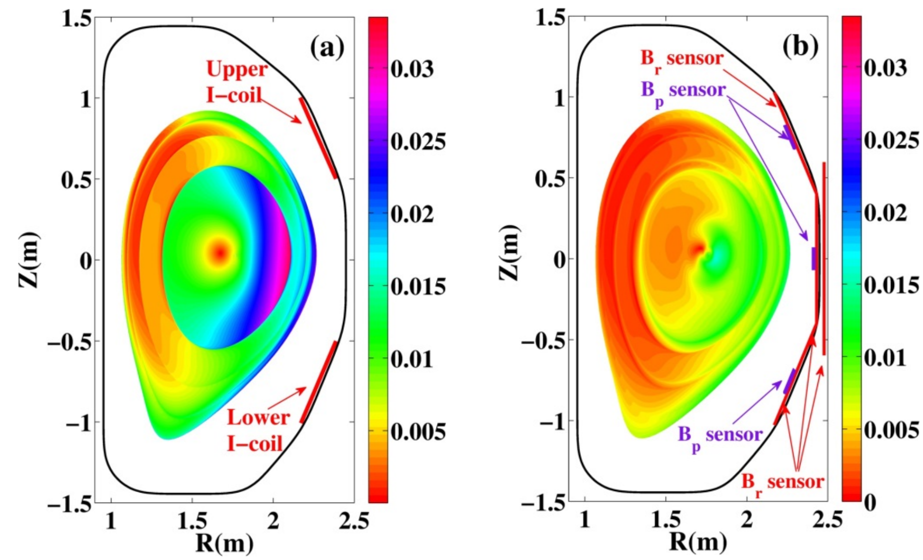

Figure 1. Illustration of the impact particle motions have on 3D equilibrium represented by the plasma displacement. The effects of micro particle motions smooth out the structure of 3D equilibrium simulated by fluid theory (a) leading to new one predicted by hybrid drift-kinetic MHD (b) that better explains the experimental observations.

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