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Understanding Plasma Rotation When Turbulence and Magnetic Ripples are at Odds

Plasma turbulence drives plasma rotation one way, ripples in the magnetic field strength drive it the other, and zero rotation can cause tokamaks to disrupt. New research clarifies this competition.

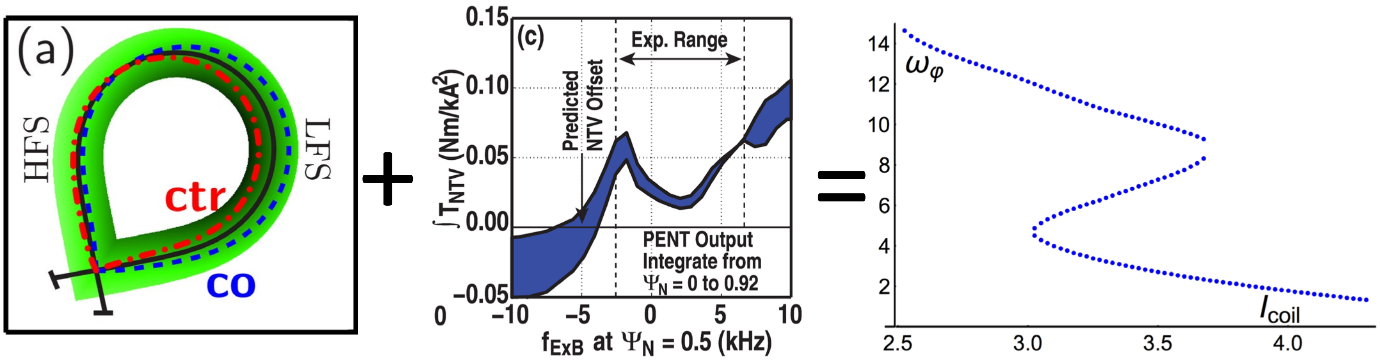

Image courtesy of Timothy Stoltzfus-Dueck and Nikolas Logan.

We combine a theory of turbulent rotation drive (left) with simulation of torque exerted by 3D magnetic field perturbations (center) to predict plasma rotation, which can take multiple values in otherwise identical conditions (right).

The Science

Plasmas in axisymmetric, magnetic confinement devices known as tokamaks tend to rotate around their axis of symmetry, somewhat like a wheel spinning on its axis. Fortunately so, because rotation can suppress instabilities that may otherwise lead to disruptions, where particles and heat suddenly escape and may damage the inner wall of the experiment. Ubiquitous microscopic fluctuations in the electric and magnetic fields ("turbulence") tend to drive the rotation in one direction; small non-axisymmetric variations in the magnetic field strength deliberately applied to stabilize the plasma edge tend to drive rotation in the other. If they cancel, the plasma may stop rotating and become unstable. Understanding how the torque forces combine to make the plasma spin is crucial for sustained high-fusion-performance in future reactors.

Scientists at PPPL have combined analytical formulae of the turbulent effects with numerical calculations of the other sources of torque to predict plasma rotation under experimentally relevant conditions, for which both effects are comparable in magnitude. Surprisingly, the predicted rotation exhibits "hysteresis," which means that the plasma can be in one of two different rotation states at otherwise identical plasma conditions depending on the history of the discharge.

The Impact

If the plasma does not rotate, it may be driven unstable by magnetic interactions with the conducting wall of the vacuum vessel. ITER and any future tokamak fusion reactors will not be able to drive enough rotation externally and will depend on plasma turbulence and the 3D magnetic fields to spin the plasma. Quantitative predictions of the rotation are essential.

Summary

The theoretical transport model that describes the effect of turbulence shows that the plasma rotation depends on the external torque. This torque may stem from the non-axisymmetric variations, so called 3D magnetic ripples that affect rotation somewhat like how small bends and buckles cause a spinning wheel to wobble, or from the injected energetic neutral particles used to heat the plasma, which exert a spinning force. The torque force from 3D ripples depends strongly on the rotation. Combining the theoretical model with the numerical calculations allows a prediction of the edge plasma rotation in conditions where both turbulence and 3D magnetic fields are important.

In many cases, the predicted rotation may exhibit hysteresis. If the rotation is near zero, the 3D-ripple torque can be especially strong, defeating the turbulence-driven torque to keep the rotation near zero. For faster rotation, the 3D-ripple torque often becomes weaker, and the rotation can be controlled by the then-stronger rotation-independent turbulent rotation drive.

Quantitative predictions of rotation with both turbulence and 3D ripple torque are difficult but crucially important in order to protect ITER and future fusion reactors from possible disruptions due to unexpected low-rotation states. These predictions will be validated in upcoming experiments on tokamaks with 3D field capabilities.

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Publications

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