Dancing Magnetic Field Lines in Simulations of the Edge of Fusion Devices

For the first time, kinetic computer simulations are able to include the effects of fluctuating magnetic fields on turbulence in the edge of fusion power devices.

Snapshot from a video showing self-consistent bending and moving magnetic field lines (color lines) interacting with turbulent plasma density fluctuations (color scale) in the edge region of a tokamak. Left: top view, Right: side view. (Click for full video.)

The Science
Past kinetic simulations of plasma turbulence in the edge region of fusion devices have assumed that the magnetic field lines are rigid and that the plasma turbulence was caused by fluctuations only in the electric field. Including the self-consistent movement of the magnetic field has been hard because it involves a delicate balance of forces on electrons, which are much lighter than ions. Recent computer simulations using a combination of advanced algorithms are now able to do these calculations with sufficient accuracy that they can include fluctuations in both electric and magnetic fields to simulate the self-consistent interactions of moving magnetic field lines and turbulent density fluctuations.

The Impact
It is important to understand plasma turbulence in the edge region of fusion devices because it affects how hot the plasma can get and thus how much fusion power is generated, and it affects how much the plasma heat is spread out when it hits solid surfaces inside the fusion device. More work is needed to develop sufficiently realistic simulations of turbulence in the edge region of tokamaks, but the present results demonstrates that such simulations are possible. This is an important milestone on the road to developing comprehensive simulations that can be tested against present fusion experiments and used to help optimize the design of future fusion power plant concepts.
Summary
Many past computer simulations of turbulence in the edge region of tokamaks used fluid approximations. These codes have provided a lot of insight into the nature of this plasma turbulence, and have been fairly sophisticated within the fluid framework, including effects such as the interaction of the turbulence with magnetic field lines, causing them to fluctuate and move. But for more accurate predictions, particularly for hotter fusion plasmas, we need to go beyond the fluid approximation to use gyrokinetic equations that track the distribution of particles in a higher dimensional phase space. Handling magnetic fluctuations in gyrokinetic edge simulations has historically been difficult. It involves a delicate balance of forces on very light electrons, which are less than 1/3000th of the mass of deuterium ions. Because of this, past kinetic simulations of tokamak edge turbulence neglected the motion of magnetic field lines by making an electrostatic approximation, where the turbulence was driven only by fluctuations in the electric field, and the magnetic field was assumed to be static. By using advanced numerical algorithms (certain versions of Discontinuous Galerkin algorithms), these new simulations are able to preserve important balances that occur in the governing equations, so that for the first time they are able to handle magnetic field fluctuations that self-consistently interact with plasma turbulence. This could eventually lead to more accurate simulations of tokamak turbulence and help search for ways to improve the performance of future fusion power plants.

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Publications