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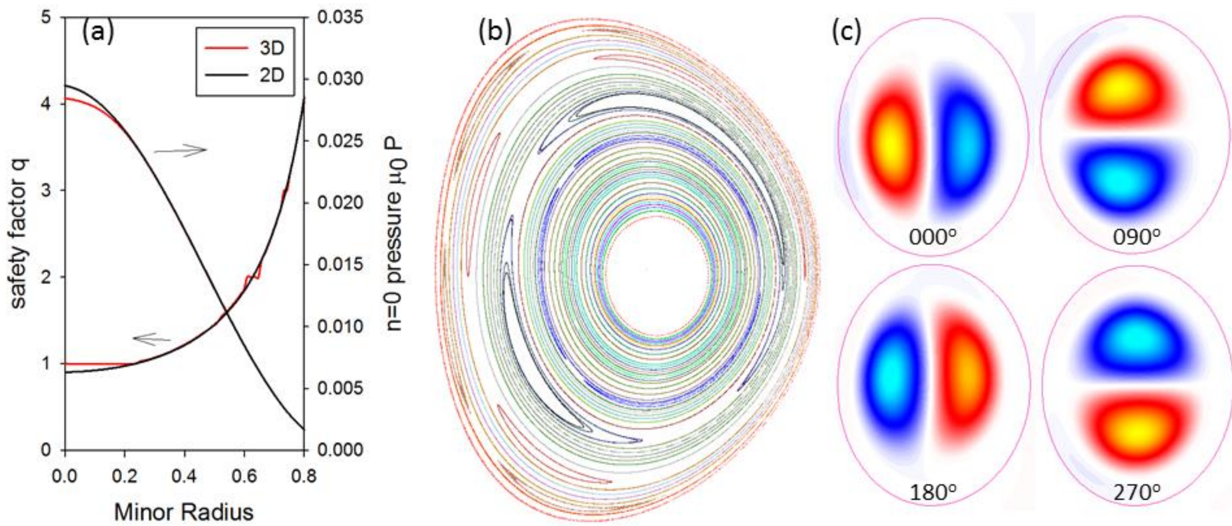
Self-organized Stationary States of Tokamaks

How a particular mode of tokamak operation can avoid current peaking and the internal kink instability through a dynamo action.

Image courtesy of PPPL



(a) Comparison of q-profile and toroidally averaged pressure for stationary state 3D run and 2D run with exactly the same transport coefficients. (b) Poincaré plot of the magnetic field in the final state with (2, 1) and (3, 1) islands present. Center volume has q = 1. (c) Contours of electrostatic potential produced by the stationary interchange mode interior to the q = 1.01 surface at 4 toroidal angles.

The Science

In most tokamak discharges, the plasma current slowly peaks in the center of the discharge until it becomes unstable to an internal kink mode. This instability (known as the sawtooth) temporarily flattens the central current, at which time it begins to peak again. Through high-performance computer simulation, we have found another mechanism for preventing the current from peaking that involves a self-organized dynamo action. This can likely explain the physics behind experimentally observed non-sawtoothing discharges such as the “hybrid” mode in DIII-D.

The Impact

While the periodic internal kink instabilities (sawtooth oscillations) are generally benign, there is reason to believe that they are best avoided in burning plasmas such as will occur in ITER. The presence of high-energy fusion products (energetic alpha-particles) can increase the amplitude of these oscillations. Sufficiently large oscillations can excite other nonlinear instabilities such as the neoclassical tearing mode or edge localize mode. In some cases, the deformations caused by these different plasma instabilities can interact, potentially causing a major disruption which terminates the discharge. The non-sawtoothing self-organized hybrid state found here avoids the root source of these potentially harmful deformations.

Summary

For certain global parameters, regardless of the initial state, the plasma profiles will evolve into a self-organized state with the central safety factor q (ratio of times a given magnetic field line travels around the torus the long way to the short way) slightly above unity and constant in a central volume. Such a large shear-free region with q just above unity is known to be linearly unstable to interchange modes driven by any non-zero pressure gradient. Unlike an unstable configuration with a q = 1 resonant surface in the plasma, the unstable linear eigenfunction for an ultralow shear configuration with q just above 1 throughout a volume is distributed out to the region where the shear begins (about the q = 1.01 surface) and the instability drives a strong stationary (1, 1) helical flow. The driven flow creates a stationary (1, 1) component of the electrostatic potential and of the magnetic field that combine to create a (0, 0) spatially varying "dynamo" voltage that prevents the current density (proportional to 1/q) from peaking in the center and hence maintains q slightly above unity and shear-free in the central region with a relatively broad current profile. This mechanism could explain the physics behind the non-sawtoothing "hybrid discharges" with q_0 ~ 1 that have been experimentally observed in DIII-D and many other tokamaks.

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