

Measuring Zonal Flows in High-Temperature Plasmas

The plasma in a tokamak is much like a simmering (or even boiling) pot of water or soup, with the boiling becoming stronger as the difference in the temperature between the core and edge regions of the plasma grows when more heating power is applied, just as the pot boils more strongly as the burner is turned up. A “boiling” plasma is described as being in a state of turbulence, and the small-scale chaotic motions of the plasma are termed turbulent eddies. The analogy with a boiling pot of water has important implications for improving the performance of tokamaks, because in the same way that stirring the pot can keep it from boiling too violently, we can “stir” the plasma to limit the strength of the turbulence. In fact, one of the most interesting developments in our understanding of plasmas in the last ten years has been the discovery that the turbulence actually “stirs” itself by generating flows which limit the turbulence and its associated transport. Because these flows are symmetric in the poloidal and toroidal directions (i.e. the ‘short’ and ‘long’ ways around the tokamak), they are called zonal flows; the overall structure of these flows is much like the bands on Jupiter or the jet stream in Earth’s atmosphere. Essentially, these flows rip apart the turbulence, limiting its size and strength (and thereby the rate at which they transport particles and energy). Including accurate descriptions of these zonal flows in numerical simulations of the turbulence have greatly increased the accuracy with which we can model existing experiments, and the confidence we have in predicting the performance of the upcoming ITER device.

While zonal flows have been extensively studied in numerical simulations, they have now been measured for the first time throughout a high-power tokamak. Using a technique called beam emission spectroscopy developed by researchers at the University of Wisconsin, Madison, we can track the movement of the turbulent eddies, and thereby infer the corresponding zonal flow field (similar to inferring the wind speed by watching the movement of clouds). The results have been used to qualitatively confirm many of the predicted properties of these zonal flows, including their amplitude, oscillation frequency, and lifetime, as well as their interactions with the turbulence. Our observations on the DIII-D machine are complemented by additional zonal flow measurements in a simple plasma column experiment, the CSDX machine at the University of California, San Diego. The results provide necessary experimental validation for extrapolating our models of turbulent transport to future devices such as ITER with confidence, and demonstrate the benefits of strong collaborations between universities and national laboratory facilities.

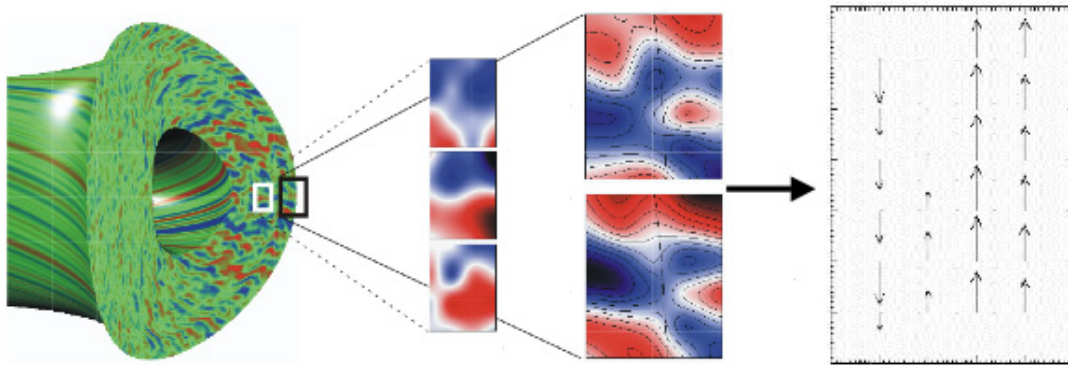


Fig. 1. Left: snapshot of a computer simulation (developed at General Atomics) of plasma turbulence in DIII-D. Middle: images of turbulent eddies obtained by beam emission spectroscopy from the actual DIII-D experiment, which are used to infer the presence of zonal flows (right).

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