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Measuring How High Temperature Plasmas Boil

New experimental measurements of plasma turbulence allow for the detailed testing and improvement of models used to predict the performance of future fusion reactors.

PHILADELPHIA, Pennsylvania, Oct. 30, 2006 – Hot, magnetically confined plasma is much like a boiling pot of water, and the intensity at which the plasma is boiling often determines how well it is confined. Such a “boiling” plasma is in a state of turbulence, and the chaotic motions of the plasma are called turbulent eddies. These turbulent eddies occur on large and small scales and are associated with the loss, or transport, of particles and energy from the confinement field. Recent collaborative experiments on the DIII-D National Fusion Facility by a team of researchers from the University of California, Los Angeles, University of California, San Diego, University of Wisconsin-Madison, and General Atomics have provided detailed measurements of the turbulence, allowing for the creation of more precise models to predict the performance of future fusion reactors.

The analogy with a boiling pot of water has important implications for improving the performance of tokamaks, fusion reactors that use strong magnetic fields to confine a donut-shaped plasma. In the same way that stirring the pot can keep it from boiling too

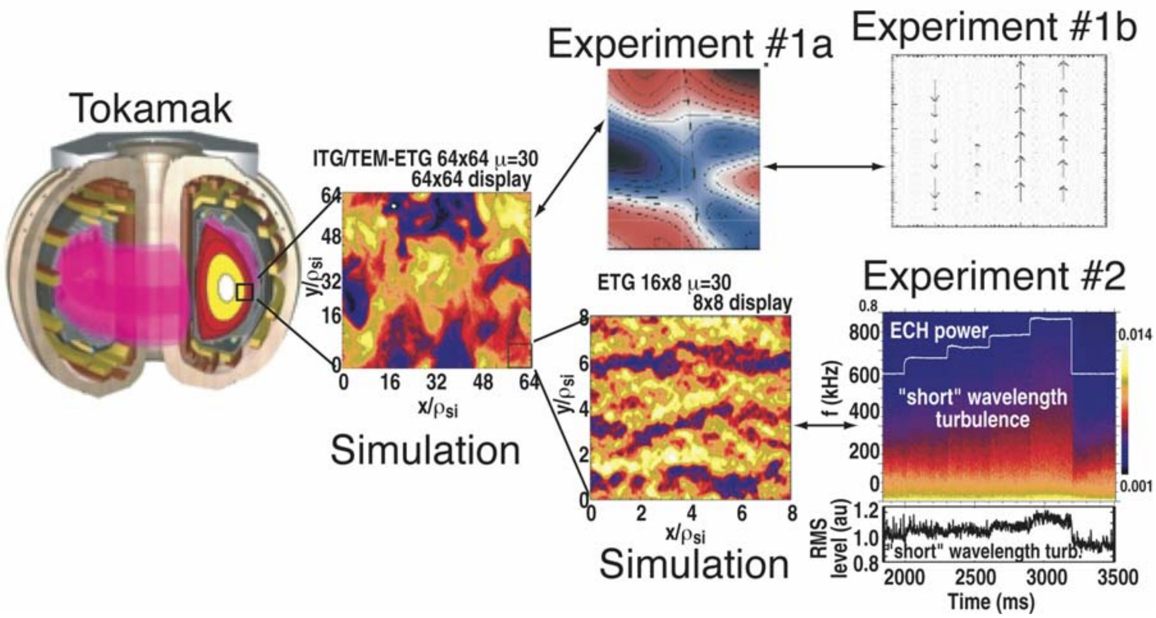

Fig. 1. Diagram of plasma in a tokamak (far left), and computer simulations (from GYRO code at General Atomics) showing different turbulence sizes. Experiment #1a shows images of turbulent eddies obtained by beam emission spectroscopy from the actual DIII-D plasma experiment which are used to infer the presence of the “stirring” flows (Experiment #1b). Experiment #2 shows color contour plot of the amplitude of “short” wavelength turbulence as a function of frequency and time as well as the increase in amplitude shown below that.

violently, we can “stir” the plasma to limit the strength of the turbulence. One of the most interesting developments in our understanding of plasmas has been the discovery that the turbulence actually “stirs” itself by generating flows which limit the turbulence and its associated transport. While this stirring has been extensively studied in numerical simulations, it has now been measured for the first time throughout a high-power tokamak by researchers at the University of Wisconsin, Madison. Using a technique called beam emission spectroscopy that tracks the movement of turbulent eddies, they were able to infer the corresponding flow fields (Experiment #1 in Fig. 1), similar to inferring wind speed by watching cloud movement. These measurements confirmed many of the theoretically predicted properties of these flows and, complemented by measurements in the CSDX experiment at the University of California, San Diego, provide necessary experimental validation for extrapolating models of turbulent transport to future devices such as ITER with confidence.

The turbulent eddies in a tokamak also occur in many different sizes, just as the Earth’s atmosphere exhibits turbulent eddies ranging in size from a small scale “dust devil” up to large scale hurricanes and cyclones. At sizes of about 2 mm or less, approximately 10-60 times smaller than the turbulence discussed above, there have been two important unresolved questions for tokamak plasmas: does “short” wavelength turbulence exist, and if so, does it impact electron heat transport? Recent experiments at the DIII-D National Fusion Facility by a research team from the University of California, Los Angeles (UCLA), show that this “short” wavelength turbulence clearly exists in tokamaks, that the level of this turbulence increases as the electrons are heated (Experiment#2 in Fig. 1), and that the changes in turbulence level correlate with changes in electron heat transport. By contrast, the larger scale, long wavelength turbulence did not change. Since the heating in future fusion power reactors will be predominantly to electrons, understanding small-scale plasma turbulence may hold the key to controlling heat transport in future fusion power experiments. These new observations were made possible by advanced microwave and far-infrared diagnostic systems developed by the UCLA team, and the experiments were performed in collaboration with other members of the multi-institutional DIII-D team.

These research findings into plasma turbulence demonstrate the benefits of strong collaborations between universities and national laboratory facilities.

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