Video Imaging of Tokamak Plasma Edge Reveals Detailed Structure of Edge Turbulence

Turbulence in ordinary fluids such as water and air is responsible for most of the heat and mass flow in our everyday world, but their complicated turbulent flow patterns are still very difficult to predict and understand (as in weather forecasting). Similarly, turbulence in magnetic fusion plasmas probably causes most of the heat and mass transport that so far limits fusion reactor performance. However, plasma turbulence is even more difficult to measure and to understand than turbulence in water or air. Magnetic fusion plasmas are particularly turbulent at their edges, where the magnetic field topology changes from nested surfaces that "close" upon themselves to a magnetic field topology in which the field lines intersect the material walls of the device. Turbulence is observed to increase sharply outside this boundary. As part of the recent emphasis on the physics of transport within the magnetic fusion program, a new technique has been developed to make high resolution 2-D space movies of the plasma turbulence in this region. The typical time scale for the birth, growth, and disappearance of the turbulent structures ("eddies") is ~10 microseconds. Sequential frames from such a movie are shown in the figure. Each image is taken with a 4 microsecond exposure time and represents the structure of the plasma edge turbulence within a 6 cm x 3 cm region perpendicular to the strong magnetic confining field in the Alcator C-Mod tokamak at MIT. The false color scale represents the brightness of the line emission from a puff of neutral deuterium gas that was used to illuminate the underlying plasma density turbulence. The time development in this case shows two "blobs" of density which spontaneously form and move outward (in the direction of the arrows, away from the region of “closed” magnetic surfaces), presumably causing at least part of the turbulent transport of plasma across the magnetic field. This high-resolution measurement is made possible by using a state-of-the-art, ultra-high-frame-rate CCD camera developed by Princeton Scientific Instruments. First-principles computer simulations of this turbulence have been done based on the measured plasma profiles and show encouraging qualitative agreement with the measured space and time patterns. By directly comparing measured and computed turbulence patterns we hope to clarify the underlying physics of this turbulence and eventually to be able to predict and optimize the turbulence-driven transport in a magnetic fusion reactor.

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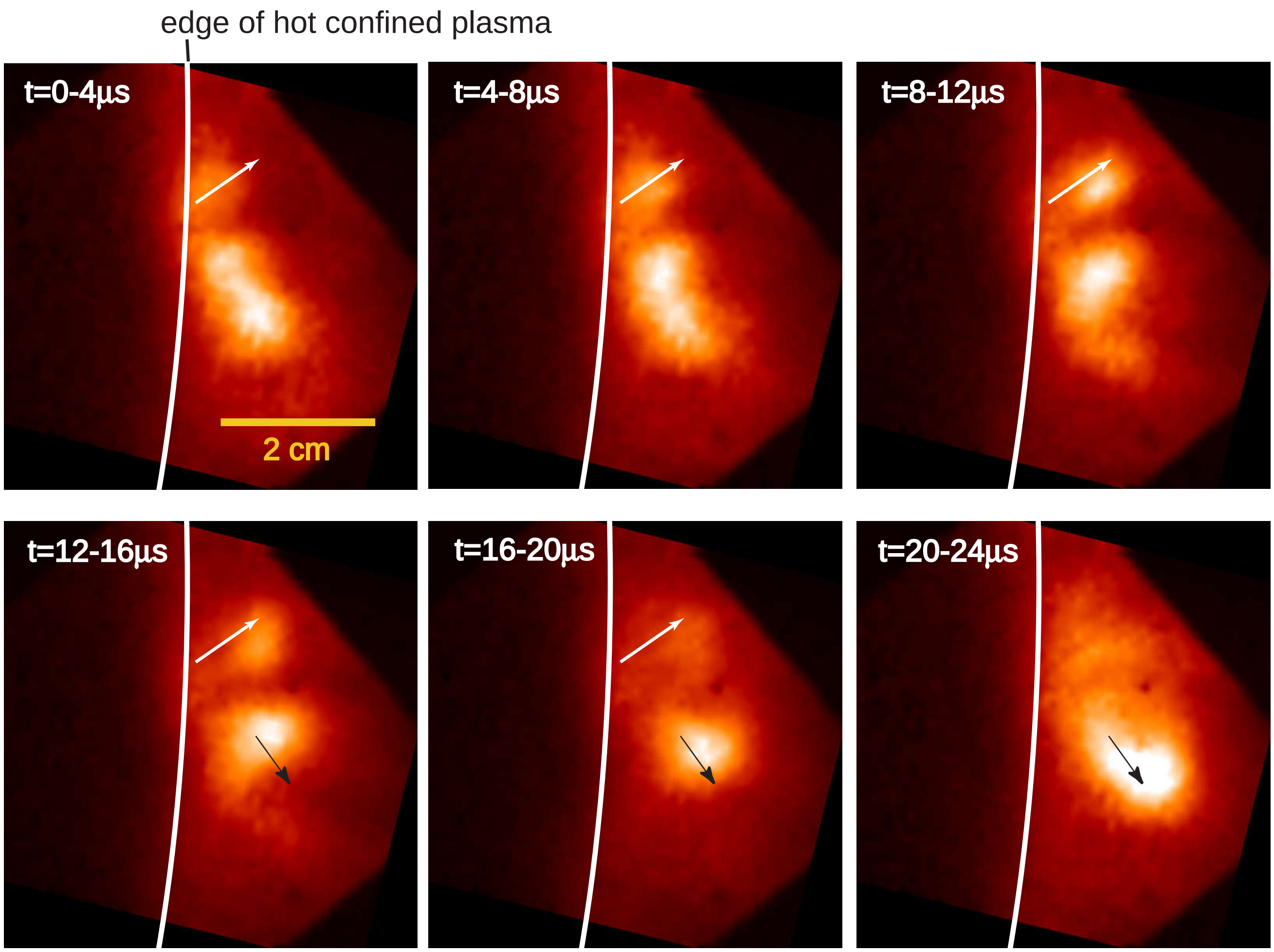

Images of the edge of the Alcator C-Mod tokamak showing the space and time evolution of the edge turbulence. The white line shows the location of the boundary between the "closed" and "open" magnetic field lines. The white arrow shows the outward (toward the vessel wall) and upward movement of one "blob". The black arrow indicates the movement of another. Both arrows remain in the same position frame-to-frame. This predominately outward movement is most likely responsible for at least some of the outward plasma transport across the magnetic field.