Sometimes it is quiet at the edge

Scientists find 'quiet periods' in the plasma at the edge of a tokamak fusion device

Perhaps the biggest challenge for a magnetic fusion reactor will be to control the plasma interaction with the wall, since the edge plasma will be above 10,000 ºC, while the material wall must be below 1000 ºC. Therefore it will be necessary to have a clear understanding of the way the edge plasma makes contact with the wall. To do this it would be helpful if the plasma was "quiet" at the edge. However, the edge of a tokamak fusion plasma is often violently unstable, with filamentary "blobs" of plasma spontaneously being created and flung out toward the wall at the speed of a rifle bullet - about 1 kilometer per second. Researchers have believed that only when the plasma edge makes a sudden transition from the L-mode (low) confinement regime to the H-mode (high) confinement regime is this edge turbulence is relatively quiet.

During experiments over the past year on the low-aspect ratio tokamak NSTX (National Spherical Tokamak Experiment) at the Princeton Plasma Physics Laboratory (PPPL), scientists discovered that quiet periods in edge turbulence can occur well before the L-H transition. The edge turbulence in this experiment was visualized using ultra-high speed cameras viewing the visible light emitted by neutral gas in the edge, as shown in the figure below. Images like these have now been made at up to 400,000 frames per second, allowing the structure and motion of the turbulence to be measured for ~30 milliseconds preceding the L-H transition in NSTX, which is long compared with the ≤ 1 millisecond transition itself.

Images such as those in this figure showed a surprising result: that there were transient quiet periods in the edge turbulence occurring for at least ~30 milliseconds preceding the L-H transition, during which time the edge turbulence was temporarily suppressed in a nearly-periodic cycle with a frequency of about 3 kilohertz. In this figure taken about 7 milliseconds before the L-H transition, the first three rows (lasting about 100 microseconds) show the turbulence and blob formation normally characteristic of an L-mode plasma, while the next 2 rows (lasting about 70 microseconds) show a 'quiet period' similar to that seen during H-mode plasmas. This quiet period was then followed by another turbulent period, as showed in the bottom two rows, with this cycle continuing at about 3 kHz at least 100 times preceding the L-H transition. Even though these transient quiet periods in L-mode are very similar to the images seen during H-mode, they did not systematically change as the L-H transition time was approached, so they are apparently not the trigger mechanism for the transition.

So what causes these quiet periods ? Recent analysis of the 2-D motion of the turbulence in these images by PPPL and the University of Colorado has shown a strong and surprising correlation between these quiet periods and the *direction* of the flow speed of the turbulence within this field of view. During the quiet periods

the turbulence flows at approximately 2-4 kilometers per second upward just inside the magnetic separatrix (i.e. the left of the solid white line in each frame), while during the turbulent periods the turbulent structures suddenly flow in the *opposite* direction.

Similar 'zonal flow' oscillations have been measured previously in other plasma devices, and have been compared to the bands of fluid flow seen in the atmosphere of planets such as Jupiter. Indeed, specific theoretical calculations for these NSTX plasmas by IPP Garching and Lodestar Research have predicted edge zonal flows should appear at a frequency about 3 kilohertz (to within about a factor-of-two). Thus these edge zonal flows may be causing the quiet periods in NSTX, but not the L-H transition itself.

A third surprise occurred this summer when a follow-up experiment was done to determine the scaling of the frequency of the quiet periods with the magnetic field in NSTX. During this experiment the spectrum of quiet periods was found to be considerably more complex than before, with a zonal flow frequency that jumped irregularly in time within the range 1-6 kHz, rather than having a near-periodic oscillation at about 3 kilohertz. Furthermore, similar zonal flow oscillations have now been seen during H-mode, as well as L-mode plasmas. Clearly there remain many fascinating and important unanswered questions concerning the edge turbulence, zonal flow, and L-H transition physics in tokamaks.

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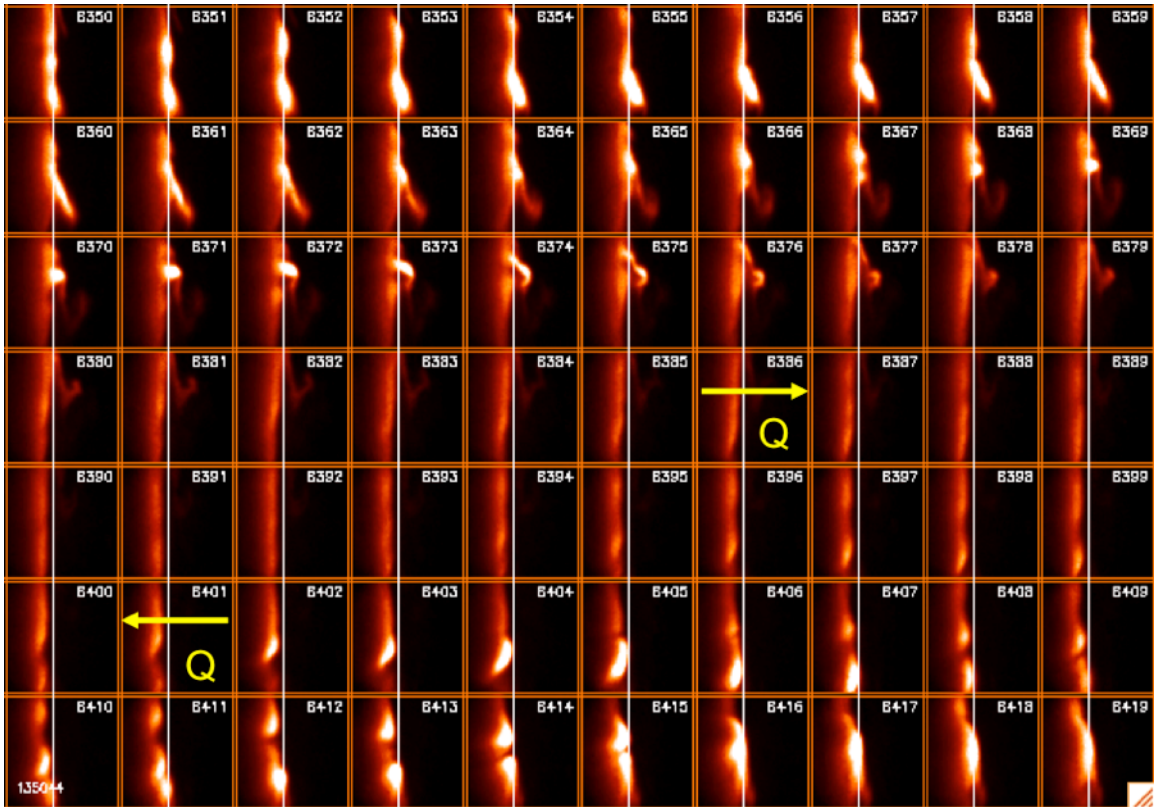

Two dimensional images vs. time of the edge turbulence in NSTX showing a quiet period between the frames labeled with "Q". These images were made at a rate of 3.5 μs/frame and cover 25 x 25 cm in the radial vs. poloidal direction near the outer midplane (radially outward to the right). The vertical white line in each frame is the magnetic separarix.