Measuring Electron-Scale Turbulence in a Fusion Plasma

Electron-scale turbulent fluctuations have been measured across a range of characteristic eddy scale lengths in a variety of plasma conditions.

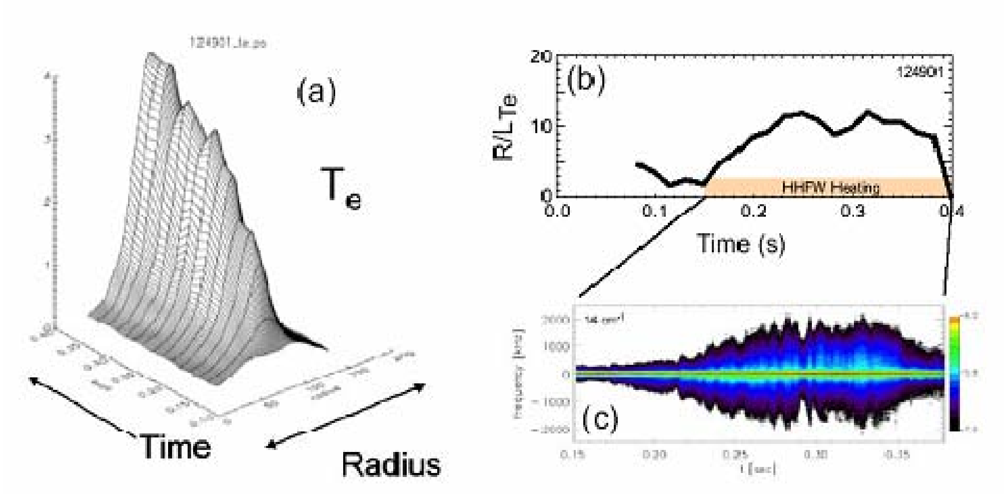
Fusion reactors require a high plasma temperature and pressure for an efficient generation of fusion power. These high temperatures are easier to achieve and maintain if the energy of the plasma is well contained. Energy leaking across the confining magnetic fields, and ultimately out of the plasma, must be minimized. Turbulent eddies involving both the plasma ions and electrons are a primary source of energy loss in magnetically confined fusion plasmas as they transport heat far faster than is predicted by considering only the standard particle orbits in the presence of the confining magnetic fields. In conventional tokamaks, this energy is lost predominantly through turbulence on the scale of tens of ion gyroradii, which is driven by gradients in the ion temperature that contribute to the growth of these turbulent modes.

The National Spherical Torus Experiment (NSTX) at the U.S. Department of Energy's Princeton Plasma Physics Laboratory produces a plasma that is shaped like a sphere with a hole through its center, different from the "donut" shape of a conventional tokamak. Measurements of the ion heat transport in the NSTX support predictions that the ion-scale turbulence can be stabilized by NSTX's magnetic geometry and plasma profile characteristics. Yet, energy loss on NSTX still remains comparable to that on conventional tokamaks though, conversely, through the electron thermal channel. This dominance of electron thermal transport combined with the low magnetic field, and thus large electron gyroradius, makes NSTX an important and unique test bed for measuring electron-scale turbulence and comparing to theoretical predictions of electron turbulence theory and electron thermal transport. This understanding is of particular importance to the upcoming International Thermonuclear Experimental Reactor, where electron transport and turbulence will play an important role due to the heating of the electrons by the alpha particle fusion products.

Measurements of these electron-scale turbulent eddies have been obtained on NSTX in collaboration with UC-Davis using a scattering system based on a high power 280-GHz microwave probe beam. This signal, scattered from the turbulence fluctuations, is ~~then~~ collected at multiple angles which provide a localized measurement of the turbulence over a range of scale lengths from ~10 to 60 electron gyroradii. Microwave scattering measurements from experiments on NSTX have shown varying fluctuation behavior not only at different locations in the plasma but also at the different scale lengths covered by the multi-channel collection system, highlighting the importance of measuring the turbulence both locally and over a range of eddy sizes.

Analysis of the power spectrum from the collected signals provides a measure of the amplitude of these fluctuations along with their fluctuation frequency. Similarly to the ion-scale turbulence, the growth of these electron-scale instabilities is predicted to depend on the gradient of the electron temperature. Recent experiments on NSTX have used radio-frequency heating to increase the plasma electron temperature, and show a connection between the electron temperature gradient and the amplitude of these electron-scale turbulent fluctuations which is consistent with predictions from linear and non-linear gyrokinetic code simulations of electron-scale microinstabilities.

The results from this and other experiments investigating electron turbulence and transport have just begun to scratch the surface of the rich, underlying physics of this complex, dynamical system. Future work will extend this understanding and ultimately allow a more confident prediction of the performance of upcoming, high-power fusion devices.



This figure shows the time history of the electron temperature radial profile of the NSTX plasma (a), along with a measure of the normalized temperature gradient (b), and the electron-scale turbulent fluctuation amplitude (c). The radio-frequency heating is applied from 0.15 - 0.4 seconds resulting in an increase in both the electron temperature and the normalized gradient, with a corresponding increase in the fluctuation amplitude and a broadening of the spectrum. This fluctuation measurement is localized to the high electron gradient region at 119 cm.

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W. Lee, “In-situ calibration of the high-k scattering system on NSTX”, TP8.71

E. Mazzucato, “Experimental investigation of turbulent fluctuations with the scale of collisionless skin depth in NSTX plasmas”, CO3.2

H.K. Park, “NSTX High-k Scattering System on NSTX: Status and Plan”, TP8.69

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K. Tritz, “The relationship between Type I ELM severity and perturbed electron transport in NSTX”, NI1.5

H. Yuh, “Internal transport barriers in NSTX reversed-shear plasmas”, CO3.3