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FIRST OBSERVATION OF REDUCED CORE ELECTRON TEMPERATURE FLUCTUATIONS AND INTERMEDIATE WAVENUMBER DENSITY FLUCTUATIONS IN H- AND QH-MODE PLASMAS

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First Observation of Reduced Core Electron Temperature Fluctuations and Intermediate Wavenumber Density Fluctuations in H- and QH-mode Plasmas

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In this paper, we report the first observation of reduced low-*k* core electron temperature and intermediate-*k* density fluctuations in H- and quiescent QH-mode on the DIII-D tokamak. Low-wavenumber density fluctuations ($k_\theta \rho_s \leq 0.3$) are known to be locally-reduced as the edge transport barrier forms during the L- to H-mode transition [1]. However, the potential role of temperature fluctuations and higher wavenumber density fluctuations has not been previously addressed. In DIII-D, L-mode electron temperature fluctuation levels ($0.5\% \leq \tilde{T}_e/T_e \leq 2\%$ for $k_\theta \rho_s \leq 0.3$, $f \leq 150$ kHz) as measured by correlation ECE (CECE) radiometry [2]) are observed to decrease by at least a factor of four in H- and QH-mode regimes (Fig. 1, $r/a = 0.7$). In H-mode and during the entire QH-mode phase, the fluctuation level stays at or below the CECE statistical detection limit [0.33%, dashed line in Fig. 1(e)]. In addition, recent Doppler back scattering data (Fig. 2) indicate that intermediate wave number density fluctuations ($1 \leq k_\theta \rho_s \leq 2$) are also reduced substantially in these regimes for $0.65 \leq r/a \leq 1$.

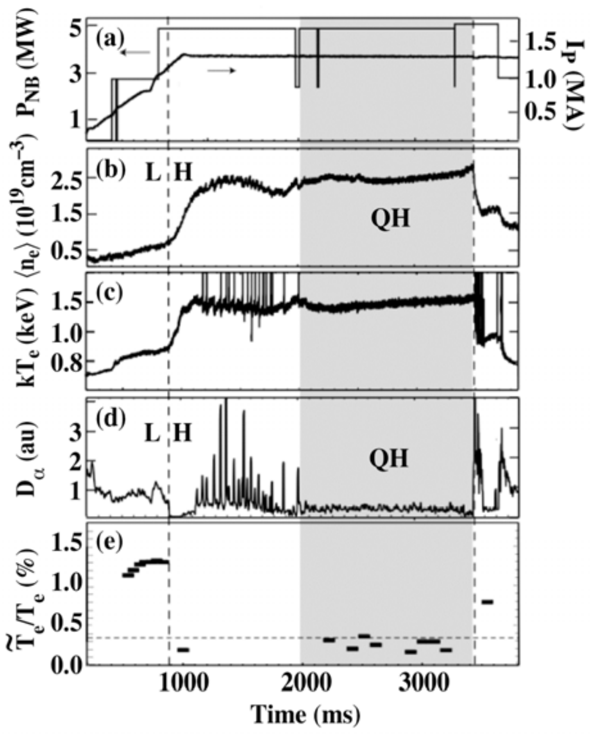

Fig. 1. (a) Neutral beam power and plasma current, (b) line-averaged density, (c) electron temperature at $r/a = 0.7$, (d) D_α line emission intensity, (e) normalized electron temperature fluctuation level for shot 125113. L-H and H-L transitions are indicated by vertical dashed lines; the QH-mode phase is shaded.

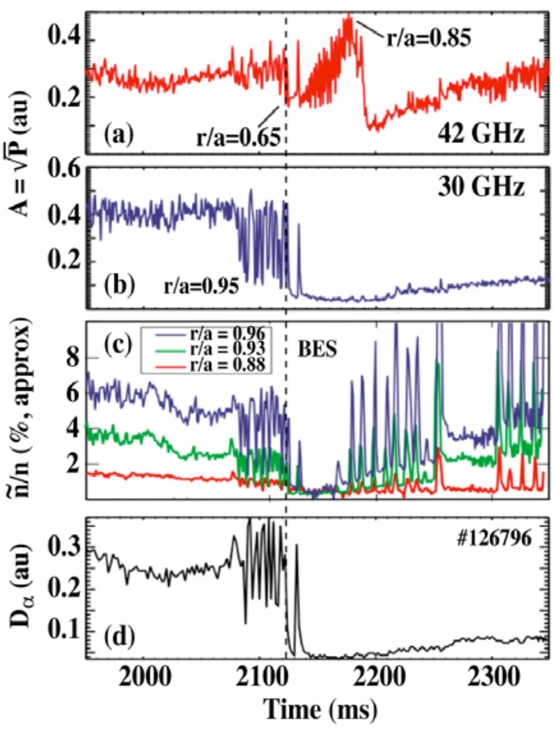

Fig. 2. (a) Backscattered signal (f = 42 GHz with cut-off present, localized as shown, $k_\theta \sim 6$ cm^{-1} (r/a~0.65, 2100 ms), $k_\theta \sim 4$ cm^{-1} (r/a~0.9, 2170 ms); (b) 30 GHz (r/a=0.95, $k_\theta \sim 3$ cm^{-1}); (c) relative density fluctuation level at low wave-number $k_\theta < 3$ cm^{-1} (BES); (d) D_α signal across the L-H transition (dashed line).

These reductions may help explain the reduced electron heat transport in H-mode. The combination of low-*k* and intermediate-*k* fluctuation diagnostics allows a more complete picture of the L-H transition to be drawn. At the time of the L-H transition, the 42 GHz back-scattered signal (*r/a*=0.65, proportional to density fluctuation level at a selective intermediate wavenumber with a resolution $\Delta k_\theta \sim \pm 1$ cm^{-1}) decreases simultaneously with the reduction of the D_α signal on a 1 ms timescale [Fig. 2(a)]. After the H-mode transition as the density pedestal evolves, the measurement location moves radially outward due to increasing plasma density. The backscattered signal initially increases indicating increasing density fluctuation levels as the edge pedestal region is approached. However, a large reduction is seen as the probe location reaches the pedestal top (*r/a* = 0.9). A second intermediate-*k* signal [Fig. 2(b), $k_\theta \sim 3$ cm^{-1}, localized in the pedestal at *r/a* ~ 0.95 in L- and H-mode] shows an order-of-magnitude reduction at the transition on a 100 μs timescale. A radial profile of the intermediate-*k* density fluctuation level after the H-mode transition [in arbitrary units, obtained from mapping the time evolution of the data shown in Fig. 1(a) using profile reflectometry] is shown in Fig. 3.

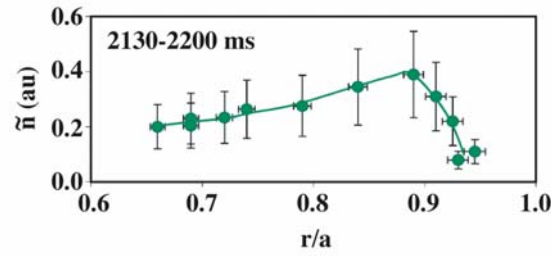

Fig. 3. Radial profile of intermediate-*k* density fluctuation level in H-mode; the error bars represent uncertainties in the scattering volume.

Core backscattering data ($k_\theta > 7$ cm^{-1}, $r/a \geq 0.5$, not shown) and intermediate-*k* FIR scattering data (not shown) also indicate reductions of $\tilde{n}/n$ in this intermediate-*k* (TEM) range. For comparison, the reduction of low wavenumber ($0 < k_\theta < 3$ cm^{-1}) density fluctuations in the pedestal, as measured by beam emission spectroscopy (BES) is shown in Fig. 2(c).

Measurements in L-mode show low-*k* temperature fluctuation levels are similar in magnitude to low-*k* density fluctuations levels [3,4]. The anomalous electron heat flux driven by electrostatic fluctuations is given by [5]:

$$Q_e^{fl} = 3/2(nk_B T_e)/B_t\left(\left\langle(\tilde{T}_e/T)\tilde{E}_\theta\right\rangle + \left\langle(\tilde{n}/n)\tilde{E}_\theta\right\rangle\right) \quad . \tag{1}$$

Here, n, T_e, and B_t are the density, electron temperature, and toroidal magnetic field, respectively, $\tilde{n}$, $\tilde{T}_e$, and $\tilde{E}_\theta$ are the density, electron temperature, and poloidal electric field fluctuation levels, with the brackets denoting a time average. Hence, in the absence of phase measurements between the various parameters, it must be concluded that $\tilde{T}_e$ and $\tilde{n}_e$ fluctuations are equally likely to contribute to the observed L-mode electron heat transport. The observed reduction of electron heat transport in H- and QH-mode ($\chi_e^{QH}/\chi_e^{L} < 0.25$, [6]) suggests that temperature fluctuations potentially play a major role in anomalous L-mode electron heat transport. Using linear stability calculations with the TGLF code [7], the observed low k_θ temperature fluctuations ($k_\theta \rho_s \leq 0.3$) are attributed to ion temperature gradient (ITG) modes stabilized by ***E*x*B*** shear at the L-H-mode transition. In H- and QH-mode, the ***E*x*B*** shearing rate is found to exceed the calculated linear growth rate for $k_\theta \rho_s \leq 0.6$. Doppler backscattering measurements of time-dependent shear flows (zonal flows) in L- and H-mode and their potential effect for intermediate-*k* turbulence regulation will also be discussed. The observed reduction of core electron temperature fluctuations and intermediate-*k* density fluctuations in H- and QH-mode are fundamental new observations that provide a fresh perspective on the physics of tokamak electron heat transport.

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